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THE COMMERCIAL APPLICATION OF MISSILE/SPACE TECHNOLOGY

PARTS 1 and 2

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THE COMMERCIAL APPLICATION OF MISSILE/SPACE TECHNOLOGY

Parts 1 and 2

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INTRODUCTION

This report is concerned with the transfer of technology from missile and space programs to non-missile/space applications in the United States. It presents the findings of a University of Denver Research Institute study sponsored by a National Aeronautics and Space Administration (NASA) grant awarded in November 1961. Initial stimulation for the unsolicited proposal leading to this study came from a 1960 Brookings Institution report to NASA, Proposed Studies on the Implications of Peaceful Space Activities for Human Affairs.[1]

The objectives of the study as set forth in the NASA grant are:

> Identification of tangible economic non-space by-products of space research and development efforts, including current applications of past research and potential future applications of current research; evaluation of by-product identification techniques; and study of information flow from space research to commercial application.

The overall purpose of the study is to aid current and future efforts to accelerate transfers of technology from the nation's missile/space programs to the commercial sector of the economy by identifying instances of transfer and by attempting to provide some understanding of the transfer process.

The logic behind efforts to accelerate such technological transfer is straightforward: Increased application of technology in the commercial sector of the U. S. economy is generally accepted as a desirable economic objective.* Well over half of the nation's research and development resources are being devoted to military and space programs; much new technology is being generated by these efforts. Some should have commercial application and, for the economy to receive optimum benefit of this technology, it should be applied in both the government and commercial sectors. Under these circumstances, it is desirable for military and space technology to be utilized where feasible by the commercial sector.

Viewed from a broader perspective, attempts to accelerate technological transfer take on added importance. At a time when science and technology[2] are playing a vastly increased role in the scheme of things on our planet, concern is being voiced about the increasing proportion of total United States R & D capability devoted to defense and space.[3] Discussions surrounding the implications of this trend are hampered by incomplete understanding of the interactions of technology and economic activities. Economists are becoming increasingly interested in the subject and, while they disagree on many details, it is agreed that increased technology, effectively applied, tends to increase economic well being.[4] It tends to increase the productivity of land, labor, and capital, thus resulting in higher living standards. It tends to increase a nation's economic growth rate, a nation's ability to compete in foreign markets, and a nation's ability to compete with foreign military and space powers. Its effect on the labor participation rate, and consequently on unemployment, is subject to dispute.

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* "Commercial" is used throughout the report to identify the civilian or private sector, embracing both industrial and consumer goods and services. Emphasis is placed on this sector; however, the report is concerned also with the broader concept of "non-missile/space," which encompasses the government as well as the private sectors.

The scope of our study was restricted to the transfer of space technology. Space was interpreted to include both military and peaceful space activities, hence the repeated references throughout the report and in its title to missile/space technology. It now appears that an expanded scope probably would have been more meaningful to have permitted inclusion of commercial transfers of technology resulting from non-missile/space military and Atomic Energy Commission research as well as transfers resulting from missile/space research. No clear line can be drawn between space and non-space knowledge because the two are closely interwoven.

This report is written primarily for the use of individuals in government who are concerned with accelerating technological transfer. While emphasis would have differed for an industrial audience, it is hoped that individuals in industry may find the report useful.

Several hundred persons, representing industrial firms, research organizations, government agencies, universities, trade magazines, patent law firms, and trade associations contributed information to the study effort. Acknowledgement is made of their valuable assistance, especially those who talked at length with us in their offices, often followed by telephone and written communications.

We are particularly grateful to Morton J. Stoller, Director, Office of Applications, NASA, and Louis Fong, Director, Office of Technology Utilization, NASA, for guidance and suggestions given during the project; to Jack C. Oppenheimer, former Executive Secretary of the Committee on Long Range Studies of NASA, for assistance extended in the early phases of the study; to Philip B. Yeager, Special Consultant to the Committee on Science and Astronautics, U. S. House of Representatives, for furnishing helpful background; to Robert A. Solo, National Planning Association, for valuable discussions pertaining to his project in a related area; and to Lawrence L. Rosine, Editor, Electrical Design News, for his contribution to the discussion of semiconductors and microsystems electronics.

Five members of the University of Denver Research Institute staff are principally responsible for the report: John G. Welles, Head, Industrial Economic Division and supervisor of the project; Lloyd G. Marts, Robert H. Waterman, Jr., and John S. Gilmore, Industrial Economists; and Robert Venuti, Chief, Mechanical Metallurgy Section. In addition, 27 other Institute staff members participated as consultants. Among these, special acknowledgement is extended to James F. Mahar, Senior Economist; Clinton M. Kelley, Senior Research Chemist and Professor of Chemistry; William G. Howell, Research Mechanical Engineer; Jack G. Hewitt, Jr., Research Electrical Engineer and Assistant Professor of Electrical Engineering; Robert M. Blunt, George L. Mason, and Franklin E. White, Research Physicists; Roger P. Hansen, Editorial Assistant; and Martin D. Robbins, Assistant to the Director.

SUMMARY OF MAJOR FINDINGS AND CONCLUSIONS

Primary objectives of this study were to identify tangible economic by-products of missile/space programs which have or are expected to find commercial use, and to determine the origin, and circumstances surrounding the origin, of these by-products.

Principal findings and conclusions follow:

1. Within the study objectives, the transfer of technology has been by far the most important contribution of missile/space programs to the civilian sector of the economy.

2. A portion of the technology advanced by the missile/space programs has found, and will continue to find in increasing amounts, application in commercial industry for non-missile/space purposes. The study identified 33 broad technological areas, plus several miscellaneous areas, in which transfer has occurred or can reasonably be expected to occur in the future. Within these, 185 transfer examples were documented and are described in Chapter VI in Part 2 of the report (126 of these have occurred, 59 are potential). These examples do not include all, nor can they be considered statistically representative of, the transfers which have taken place, but they do provide evidence of the magnitude, scope, and nature of the missile/space technological contribution to the commercial sector.

3. A time lag exists between the development of technology for primary missile/space use and its commercial application. Large expenditures on missile/space programs have been made only in recent years and there has not been sufficient time for many transfers to take place. It is highly probable, therefore, that most of the transfer is still to occur.

4. Relatively little importance can be attached to the direct transfer of products from missile/space programs to the civilian sector of the economy at this time. While numerous identification problems exist, the findings lead to the conclusion that product transfers have not been significant and that the term "by-product" is misleading in that it does not describe the total transfer process. It is more accurate and meaningful to consider missile/space contributions to the commercial sector of the economy in terms of the transfer of technology rather than in terms of a transfer of products.

5. Six types of missile/space contribution to the commercial sector were noted. Individual areas of transfer identified in this study embodied from one to all six types:

   a. Stimulation of basic and applied research.

   b. Development of new or improved processes and techniques.

   c. Improvement of existing products.

   d. Increased availability of materials, testing equipment, and laboratory equipment.

   e. Development of new products.

   f. Cost reduction.

6. Missile/space R & D is but one contributor to the vast store of knowledge which is the source of technology for both the government and commercial sectors of the economy. Other R & D contributors include industry, universities, and non-missile/space government agencies. Because of the interaction among all of these, attribution of a given technological advance to a particular source is often impossible.

7. The nature of the transfer process is such that it does not appear feasible to measure in quantitative terms the economic impact of the missile/space contribution embodied in identified transfers to the commercial sector, to say nothing of transfers which defy identification.

8. Insufficient understanding of the nature of the transfer process appears to have been one reason for widely divergent views on the past and future importance of missile/space contributions to commercially useful technology.

9. Diffusion of missile/space technology for secondary, or commercial, uses may be substantially slower than diffusion for primary, or missile/space, uses. Further, there are indications that informal communication channels may be more important to the transfer process than formal communication channels. Communication channels through which technological knowledge flows to secondary uses are not understood and should be the subject of further research.

10. There are apparent gaps between the persons or organizations responsible for developing missile/space technology and those persons or organizations which can give such technology commercial application. However, market requirements information must be linked with missile/space technological knowledge before commercial applications can occur. Linkages between market information and technology appear to take place more easily inside a single division of a firm than between separate divisions or separate firms. A few mechanisms for bridging these gaps between organizations with missile/space technology and other organizations with commercial marketing capabilities have been established and their effectiveness in facilitating linkages is worth investigation.

11. Present efforts to accelerate the transfer of missile/space technology to commercial application appear handicapped by insufficient knowledge of how technology is applied at the level of the firm. This study indicates that efforts to accelerate the transfer process should be accompanied by efforts to better understand the stimuli and barriers to the application of technology.

These findings are based on information obtained during January-October, 1962, from interviews with 369 persons in 189 organizations, largely industrial firms, and from 988 responses to questionnaires sent to 3,507 organizations, again largely industrial firms.

The study report is published in two forms: a short form containing only Part 1--the major findings and analyses; and a longer form containing Part 1, plus Part 2--methodology, specific examples of transfer, and discussions of the diffusion of technological information and of the stimuli and barriers to applications of technology.

Chapter I

TECHNOLOGICAL TRANSFER

The primary objective of this study was to identify and document examples of contribution from missile/space research and development to the commercial economy. The results of this identification effort are presented in Chapter VI (in Part 2) in the form of statements--or case descriptions--from companies and government agencies having direct experience with such contributions. The purpose of this chapter is to analyze and summarize these instances of transfer.

Originally, we had expected to find a rather limited number of products, processes, and materials which had resulted directly from missile/space research and which had later found commercial application--that is, by-products, or secondary and incidental results from another effort. The term "by-product" used in this connotation was not new and had been used frequently in articles and speeches in referring to any secondary commercial contribution of government supported or motivated research and development.

We found, however, after using the term ourselves (we still find it a convenient term), that it does not precisely define the missile/space contribution to the commercial economy. In the first place, "by-product" implies that the contribution comes in the form of direct and readily identifiable results of a particular effort, when in fact most contribution does not. For this reason the term is too narrow. Second, the term implies a certain unexpectedness, unimportance, and lack of strong motivation for exploitation. To the contrary, some instances of contribution from the missile/space effort are expected, may prove to be of more significance than their progenitor, and the possible commercial market is as strong a motivation for their development as their more apparent missile/space market. For this reason, also, the term "by-product" is too limiting. (The same reasoning applies to the terms "spin-off" and "fall-out" which have been used to describe this same type of contribution.)

But, all of the examples uncovered during this study had this in common: the missile/space programs had made some contribution to them. In fact, one of the major tests of whether any particular development qualified for study purposes was: Is it dependent on, or does it embody, something which can be traced to the missile/space programs? Therefore, the term "contribution," rather than "by-product," is used throughout most of the report. (Another term, "technological transfer," is also used, as will be discussed.)

The total contribution of missile/space R & D to the commercial economy is broader, more complex, more indirect, and more difficult to identify than is generally realized. The instances of contribution that may be truly called "by-products" are but a small fraction of the whole. Because of the scope and complexity of the total contribution, however, it is probably more significant than is frequently envisioned, although this significance does not appear to lend itself to quantitative measurement.

In the remainder of this chapter, we attempt to convey an impression of the nature, scope, and significance of the missile/space contribution to the commercial economy. The various forms which this contribution has taken are defined and discussed, referring to Chapter VI for examples. This chapter concludes with Exhibits A and B, which present in tabular form a summary of the types of contribution identified in the study.

Six major categories of contribution were identified: stimulation of basic and applied research; development of new or improved processes and techniques; improvement of existing products; increased availability of materials, testing equipment, and laboratory equipment; development of new products; and cost reduction. The categories are not mutually exclusive, and it is quite common to have one example embody several different categories of contribution. One or two types usually predominate, however.

Stimulation of Basic and Applied Research

Basic and applied research are stimulated in two ways: either directly through government support, or indirectly through company funding motivated by missile/space needs, and therefore by a potential missile/space market. Once the research is undertaken or completed, new scientific knowledge and technology become available for broader use than that which motivated the original funding. This general type of contribution is undoubtedly the most significant because it generates the kind of knowledge that is potentially applicable and useful to most fields of science. However, this type of contribution is several steps removed from ultimate commercial application and is therefore one of the most difficult types to identify and discuss in concrete terms.

It is impossible, except in a few cases, to relate ideas and knowledge generated on a certain missile or space project to a commercial product developed later in time. The product is more likely to be the result of a cumulative store of knowledge which includes as an inextricable part, that gained on a missile/space project. In such cases the degree of contribution cannot be assessed except, perhaps, very subjectively.

The existence and apparent importance of this type of contribution--stimulation of research--leads us to the conclusion that <u>transfer of technology, not by-product transfer, is the most significant missile/space contribution to the commercial economy.</u> Several other types of contribution also are primarily technological contributions rather than product contributions.* Therefore, we shall refer to the commercial contribution from missile/space R & D as either "contribution" or "technological transfer," these terms being more accurate and useful than "by-product."

Good examples of the type of transfer we have called "stimulation of basic and applied research" are to be found in Chapter VI under the sections entitled "Refractory Metals," "Physical Metallurgy," "Semiconductors," "Microsystems Electronics," "Fuel Cells," "Thermoelectric and Thermionic Energy Conversion," "Gyroscopes and Inertial Guidance," "Magnetohydrodynamics," and "Re-entry Simulation--The Plasma Jet." Summaries of the missile/space contribution to each technological area are presented in Exhibits A and B at the end of this chapter.

New or Improved Processes and Techniques

A second major type of contribution of the missile/space effort to the commercial economy comes in the area of new or improved processes and techniques, e.g., new ways of fabricating a material, forming a part, or scheduling a job. This type of contribution is different in degree, rather than kind, from the stimulation of basic and applied research; the ultimate contribution in either case is new technology. However, this category merits separate consideration, if only because it is a rather distinct type of contribution and examples of it are relatively easy to identify.

* Although product contribution can be considered as a type of technological contribution, product contribution is only a part of the total technological contribution.

Included in this category are new ways of performing a task which have been developed for or have received strong impetus from the missile/space program and which have had or appear to have commercial application. Most of the items represent fairly direct transfers. Good examples are contained in Chapter VI and summarized in Exhibits A and B, under the sections entitled "High Energy Forming," "Filament Winding", "Solid State Bonding," "Chemical Milling," "Medical Technology," and "Management and Control--PERT."

Product Improvement

A third category of contribution identified in the study is product improvement. It can take two forms: 1) A product is improved in design. In this category we include products which were developed originally for commercial use, which have been improved as a result of being adapted to the stringent requirements of the missile/space program, and which are sold in their improved form to the original commercial market. 2) Commercial products which benefit directly or indirectly from new or improved manufacturing, process control, or quality control techniques originally developed for the missile/space program, so that the overall number of products passing inspection is increased. Although this type of contribution is concerned with the improvement of specific products, it too can be considered a form of technological transfer.

The two most important effects of the missile/space program within the broad category of product improvement seem to be: improved reliability and improved quality. Reliability and quality were mentioned by a large number of persons contacted as being two of the most significant commercial contributions of missile/space work. Reliability and quality are of particular importance to missile/space systems, wherein the inherent unreliability of any component is compounded by the unusual complexity of the total system. Failures of such systems can cause great damage and the loss of millions of dollars. By the same token, commercial systems, particularly in the field of process control, are becoming more complex and therefore more dependent on reliability and quality of component parts. Failure of commercial systems can also be dangerous and costly. Such parallel requirements for reliability and quality motivate technological transfer.

Examples of product improvement are contained in Chapter VI and summarized in Exhibits A and B under the titles "Electronic Computer Systems," "Fluid Transfer Systems," "Resistance Strain Gages," "Instrumentation Amplifiers," and "Telemetry and Communications." A particularly illustrative section, demonstrating the importance of quality and reliability, is "Cables, Connectors, and Printed Circuits."

Materials and Equipment Availability

In certain fields, the demands of missile/space programs have not produced significant improvements in basic technology; rather, the primary result seems to be the increased availability of materials, testing equipment, and laboratory equipment made possible by intensive missile/space use. This effect tends to make such a field more useful commercially. The field of cryogenics is an excellent example. Other examples will also be found in Chapter VI, and in Exhibits A and B, within the general section entitled "Instrumentation."

New Products

A number of products have been developed for missile/space use which, later, have found commercial application in substantially their original form. This type of transfer probably represents most closely the usual connotation of the term "by-product." Examples of this type of contribution are scattered throughout Chapter VI; especially good illustrations are found in sections on "Electronic Components and Miscellaneous Systems," "Instrumentation," "Telemetry and Communications," and "Packaging and Shipping."

Movements of products from missile/space programs to commercial applications are direct and relatively clear types of transfer. Their significance individually appears to be rather small and, in total, this category seems less significant than any of the four discussed above. Part of the explanation for this is that a product, by definition, has a limited range of application, whereas the range of application of technology is very broad. This important distinction is discussed in more detail later.

Cost Reduction

A final type of contribution is cost reduction, which can take place in three ways. First, volume production for the missile/space effort can reduce the unit cost of a product to the point where commercial marketing is feasible. Examples are the solar cell and the infrared detector, both discussed in the "Instrumentation" section of Chapter VI. Second, improvement in management or production techniques can result in cost reduction. For example, the use of a clean room in a manufacturing operation can reduce the unit cost of a product (the use of clean rooms in manufacturing being a pre-missile/space technique which has been given much impetus by missile/space demands for reliability). Or, the use of Program Evaluation and Review Technique (or "PERT"--a mathematical technique for evaluating a schedule), or related scheduling techniques can reduce the overall costs of construction projects. Third, a number of companies are able to staff and maintain well equipped R & D laboratories partly because of missile/space contract research. The availability and contributions of these R & D capabilities to the commercial endeavors of these companies can be partially credited to missile/space programs and can reduce the unit cost of commercial products.

Conclusion

It is important to the understanding of missile/space transfer to realize that the various types of contributions discussed are not mutually exclusive. To the contrary, any one example of missile/space transfer is likely to contain an element of several types of contribution. Semiconductors are a good example. A considerable amount of basic and applied research has been motivated, at least in part, by missile/space electronic demand. This research has produced a significant advance in the overall state-of-the-art in the semiconductor field. At the same time, there have been many product improvements and new products developed to meet missile and space demands for reliability, miniaturization, and speed of operation. Finally, overall reduction in cost of semiconductor products has been partially caused by the existence of missile/space markets which provide a way to quickly write off R & D expenditures.

Just as failure to recognize the multiple and indirect nature of missile/space transfer has caused some persons to understate the magnitude of the missile/space contribution, so has failure to verify the authenticity of loose claims caused others to exaggerate the contribution. This study indicates that the more subtle forms of technological transfer have had, and will continue to have, the greatest impact--not the direct product type of transfer which is most often publicized.

As already noted, technology is more universally applicable than a product, which is merely a physical embodiment of technology designed to fill a specific need. The specific needs of space are often quite different from those of commercial industry and the consumer. Technology, however, is more basic and, although the impetus behind its original development may well have been to fill a specific space need, it does not take on as rigid a form as do products. Technology may be dissected, regrouped, added to, subtracted from, and tailored to meet a customer need. Having more applications, of course, technology has more potential impact.

We have found several manifestations of this truism in industry. Many individuals engaged in missile/space work are not commercially oriented and do not think in by-product or commercial application terms. They do seek, however, to disseminate contributions they make to technological states-of-the-art, and these can be retrieved through normal communications channels by commercial industry. Product transfers, when they do take place, occur more readily on an intra-firm basis than on an inter-firm basis. But intra-firm transfers are limited because many space contractors are not commercially oriented, nor do they have the necessary marketing know-how and distribution mechanism to exploit by-products. Further, commercial research is generally oriented to product improvement and new product generation through in-house development, using technology developed both in-house and by others. This process favors the transfer of missile/space technology as opposed to acceptance of missile/space products.

This emphasis on technology raises an interesting point. During World War II and thereafter, the armed services were forced to apply the existing technology to weaponry on an intensive basis, and they "used up" much of the existing store. Later, and to the present, they supported more and more basic research--or at least research on the basic side of the spectrum. The National Aeronautics and Space Administration, with its recent origin and tightly scheduled programs, is in a situation which may parallel that of the armed services during World War II. Its programs initially have largely been mission oriented, of an engineering or developmental nature. As its basic research program evolves and expands, it should contribute more to the nation's store of science and technology and more to the commercial economy.

Exhibits A and B follow, presenting in tabular form a summary of the contributions identified in this study. The detailed information from which these exhibits are drawn and which put these contributions in perspective is contained in Chapter VI.

Exhibit A

SUMMARY OF MISSILE/SPACE CONTRIBUTION BY TECHNOLOGICAL AREA

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
INSTRUMENTATION			
Resistance Strain Gages	Modern resistance strain gage developed late 1930's. New discoveries and improvements continued to present.	Required operating temperatures and other environmental factors far in excess of pre-space capabilities forced improvement of existing strain gages and development of new bonding compounds. Other missile/space requirements caused development of better readout and calibration equipment.	Major effect of missile/space programs will be to extend sphere of application of strain gage to more severe environmental conditions (particularly temperature) both for structural research and as basic transducing element in measurement of force pressure, acceleration, vibration, and shock.
Infrared Instrumentation	Infrared studies date from about 1800. Although theory involved understood for some time, widespread use of technology has fairly recent history.	Impetus given infrared research by World War II continued by needs of missile/space program. Heat-seeking guidance systems employ extremely sensitive detection devices as well as means to accurately measure and control infrared parameters. Missile/space requirements for quality infrared devices in large quantities resulted in refined and rapid production methods reducing cost of infrared devices.	Reduced costs make available range of infrared devices now employed in commercial systems. Examples include traffic control systems, machine control systems, door automation, short range communication. Several toys built as result of availability of low cost infrared detectors.
Pressure Measuring Equipment	Static pressure measurement dates to about 1640. Probably first application of dynamic pressure measurement was steam engine indicator. Continued development in fields of heat engines, propellants, and explosives led, in pre-space era, to increased need for accurate dynamic pressure measurement.	Missile/space requirements forced accelerated development of improved pressure transducers and associated equipment. Reliable measurement needed under severe environmental conditions, e.g., extremes of temperature, corrosive fluids, corrosive atmospheres, high shock and vibration levels, severe pressure overloads. Accurate dynamic pressure measurements required at frequencies up to at least 50 KC. Requirements of missile/space program created large part of present pressure transducer industry.	Examples of items with commercial potential resulting from missile/space R & D include: electronic system to recover and record accurate pressure data which would otherwise be masked and distorted by physical limitations of basic pressure sensor; and pressure transducer developed to replace liquid manometer in systems for remote indicating barometers, altimeters, air speed indicators, industrial controls.
Temperature Measuring Equipment	Temperature measuring devices with application to missile/space work primarily two types: thermocouples and resistance thermometers. Both types in common use for many years, origin dating to 19th Century.	Missile/space requirements stimulated improvements throughout temperature measurement field. Requirements particularly emphasized reliability, convenience of use, multipoint systems, quick response time, accuracy under adverse conditions.	Commercial devices coming from missile/space R & D include: improved resistance temperature detector used in jet aircraft and automatic industrial control systems; temperature transducer used in medical research to determine temperature changes in tumors; economical triple-point-of-water temperature standard.
Instrumentation Amplifiers	Various instrumentation amplifiers produced for many years. These amplifiers used in almost all scientific disciplines. Much development occurred well in advance of missile/space programs.	Missile/space requirements responsible for significant advances in state-of-the-art. Much space support directed to reducing size, weight, power requirements and making previously developed laboratory-type instrumentation amplifiers more rugged by application of recent advances in solid state electronic technology.	Significant effect of missile/space development has been to make advanced instrumentation amplifiers available at reasonable cost to commercial markets. Many devices developed for or improved as result of missile/space requirements are finding commercial use. Examples include: transistorized preamplifiers; amplifiers for data processing equipment; isolation amplifiers; and low noise amplifiers.

Exhibit A (Cont.)

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
ELECTRONIC COMPONENTS AND MISCELLANEOUS SYSTEMS			
Semiconductors	First semiconductors finding use in electronics were "Crystal and cat whisker" detectors used in radio receivers early 20th Century. These later replaced by vacuum tubes. Vacuum tube would not work at high frequency required for radar. Therefore interest in semiconductor devices revived late 1930's. Major obstacle was difficulty in producing units with identical characteristics. Point contact transistor invented 1947. Method for purifying germanium developed around 1950. Meanwhile grown-junction technique for forming PN junction being developed. Other methods for forming PN junction include alloy technique developed 1952 and diffusion technique, a closely controllable process, developed 1956. Diffusion process led to new "drift" transistor, micro-alloy diffused transistor, mesa transistor, and epitaxial mesa transistor, raising frequency limits and operating powers of transistors.	Ruggedness, efficiency, small size, low power requirements, and high frequency characteristics make semiconductor devices ideally suited for missile/space use. For this reason missile/space program stimulated research on development of new and better devices and new semiconductor materials. For example, missile/space program probably stimulated use of silicon and will stimulate use of gallium arsenide. Advances in longevity, reliability, power, operating frequency, size, switching speed, and efficiency all brought about by missile/space motivated research. Product lines expanded and costs reduced. Missile/space research accelerated whole semiconductor field.	While difficult to single out specific devices benefitting from missile/space research, manufacturers note that missile/space motivated R & D enhances commercial line and vice versa. Improved operating characteristics made possible by missile/space research carry over into commercial items. Same is true for improved manufacturing techniques. Many semiconductor devices made cheaper through sale to missile/space markets.
Microsystems Electronics	Concept not new but intensive work in field recent.	Missile/space support (direct and indirect) greatly accelerated development of working microsystems electronic circuits and helped reduce costs.	Chief commercial use at this time in computers where much additional direct transfer from missile/space program expected. Future commercial use will be widespread in both consumer and industrial electronics.
Thermoelectric Refrigeration	Peltier effect discovered in 1834. Thermoelectric cooling remained curiosity until 1940's, when semiconductor materials with high figures of cooling merit first extensively investigated.	Application of small thermoelectric cooling devices to individual electronic components in missile/space systems and future application of thermoelectric cooling to space vehicles has given some impetus to field. Missile/space effort also contributed in that it lent impetus to semiconductor field and semiconductor devices used in thermoelectric cooling. Some auxiliary power supply equipment also contributed through missile/space research.	Small commercial thermoelectric ice freezers built and installed in at least one hotel. Doubtful that much missile/space contribution embodied in these freezers. More contribution expected in future.

Exhibit A (Cont.)

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
Connectors, Cables and Printed Circuits	Connectors and cables underwent considerable improvement as result of difficulties encountered in World War II. Printed circuits developed during World War II.	Missile/space demands for quality, miniaturization, and reliability forced improvements in many types of cable, connector and printed circuit. Missile/space contribution indirect as well as direct--that is, techniques learned in making missile/space connectors reliable can carry over to commercial items.	Connectors, cables, and printed circuits used throughout electronics. Highly reliable components coming from missile/space program have particular application in automation and computer fields where complexity of systems makes component reliability unusually important.
Display Systems		Needs of missile/space programs generated systems for displaying data visually. In some cases, missile/space scientific achievements made certain display systems feasible. Such systems used for instruction or presenting data pertaining to actual situation.	Many systems developed originally for missile/space use found other commercial use.
Miscellaneous	In electronics field missile/space work also stimulated: development of new kind of brushless alternator; improvement in several resistors and capacitors; development of electronic scanning star tracker which has potential in ship navigation; development of rotary relay; development of new DC power supply; development of line of commercial recorders; development of cigar sorting machine.		
CONTROL SYSTEMS			
Gyroscopes and Inertial Guidance	Gyroscope first used in 1852 to demonstrate Earth's rotation. First practical gyrocompass developed 1908. Early inertial guidance work started about 1945 in United States at MIT.	Missile/space effort primarily responsible for stimulating work in new science of inertial guidance. Inertial guidance systems greatly reduced in weight since early models. More significant, accuracy of inertial guidance improved by several orders of magnitude. With this improvement came corresponding improvements in component parts of inertial guidance systems, e.g., gyroscopes.	Inertial guidance systems or inertial guidance principles developed originally in missile/space program used in aircraft and atomic submarines. Use of inertial guidance in future supersonic commercial aircraft expected. Improved gyroscopes coming from work in inertial guidance have found non-space application as part of improved gyrocompasses.
Electronic Computer Systems	Basic computing principles go back to machine built by Pascal in 1642. First electronic digital computer completed in 1946.	Contribution of missile/space program primarily one of product improvement: miniaturization, high reliability, new and better input-output techniques; improvements in certain aspects of computational speed. In addition, various missile/space oriented government agencies and companies provided market for special purpose, scientific and more sophisticated computers.	Commercial application of computers widespread. Ultimate effect of missile/space inspired improvement difficult to identify but will probably be correspondingly broad. Most obvious commercial application is in automation where needs for reliability are as severe as in missile/space program and where data input-output requirements are similar.
POWER SOURCES			
Solar Cells	First silicon solar cells produced early 1950's. Much related discovery and development preceeded this, dating back to experiments on photovoltaic effect in 1839.	During late 1950's, government agencies interested in missile/space activities began to support R & D on solar cells. A major contribution of missile/space program has been to provide large market for solar cells, significantly reducing price, making less efficient cells economically feasible for commercial use.	Solar cell has been utilized as power source for portable radios, emergency call system on a Los Angeles freeway, telephone system in South Africa, community listening center in some underdeveloped countries.

Exhibit A (Cont.)

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
Thermionic and Thermoelectric Energy Conversion	Ability of hot cathode and collector in vacuum to supply power to external electric circuit long known. Phenomenon remained experimenter's curiosity until 1958. Since 1958 much effort expended to make practical thermionic convertors. Possibility of power conversion by thermoelectric devices began late 1930's and has continued to present.	Appears that space effort has given much support to work in field of thermionic and thermoelectric energy conversion. Relatively efficient and lightweight sources for small scale portable power conversion equipment were among early goals of this endeavor.	Radioisotope fueled thermoelectric conversion generators first demonstrated for terrestrial application improved by space application requirements. They are used in automatic meteorlogical data transmitting radio station and other uses underway. Thermionic convertors have potential for use as topping devices in central power stations.
Fuel Cells	General foundation for fuel cell studies laid at beginning 19th Century. Attempts to construct fuel cells extensive during 1890's and early 1900's. During late 1930's work began on Bacon cell. Not until after World War II did great interest arise.	Large amount of work on fuel cells in progress, a portion of which missile/space oriented. Principle contribution of space effort appears to have been in development of some types of regenerative systems and in general financial and moral support of already going development.	Potential applications of fuel cell include use as a prime mover for automobiles and trucks. Also can be used in remote stations and buoys as power supply or replacement for conventional battery.
Magnetohydrodynamics	Several patents granted, dating back 50 years which deal with production of electric current as result of motion of conducting fluid relative to magnetic field. Inadequate understanding of phenomena involved prevented exploitation.	ICBM re-entry problem became important in 1950's. Later problems in space propulsion gave emphasis and support to studies of high temperature properties of gases and interaction of conductive gases with electrical and magnetic fields.	Magnetohydrodynamic generator for central station power plant application under development. Appears good possibility. Principle advantage is higher thermal efficiency.
PROPULSION			
Cryogenics	History traced to 1860's. Liquifaction of air possible late 1800's. Demand for cryogenic fluids increased during World War II.	Theoretical background developed before missile/space era. Unique missile/space requirements led to new developments and improved techniques in processing, storing, handling cryogenic fluids. Result: increased availability of cryogens, equipment, and instrumentation for both missile/space and non-missile/space use.	Main commercial benefit of missile/space contribution in field of cryogenics is increased availability of cryogens and equipment and facilities for handling cryogens, making possible broader use of cryogens, e. g., in truck refrigeration systems and private research.
Fluid Transfer Systems	Fluid transfer systems old as devices, e. g., steam engine, that use fluid as working medium.	Variety of liquids used in missile/space propulsion systems brought new problems to fluid transfer systems. Liquids can be noxious, highly reactive, intractible, or self-igniting. High and low extremes of temperature and pressure are also important problem. Components used in solutions to these problems basically like their counterparts in earlier systems.	Commercial systems benefit from emphasis placed on better components and research toward this end. Numerous valves, seals, pumps improved to meet missile/space requirements and are finding commercial use.
Miscellaneous	Availability of high strength (90 percent) hydrogen peroxide largely result of missile/space requirements. Since hydrogen peroxide is useful material for introduction of active oxygen into numerous commercial compounds, its availability has had salutary effect on growth of numerous oxygen containing chemicals.		

Exhibit A (Cont.)

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
FABRICATION			
Filament Winding	Theory evolved about 1947 and testing started. Early uses for filament winding (due to high strength-to-weight ratio of filament wound structures) included high pressure bottles for jet aircraft starters, aircraft hydraulic systems, high altitude research rockets.	Missile/space effort made extensive use of filament wound structures for rocket cases and pressure bottles. In so doing, it advanced technology considerably. Much research and development on resins, glass filaments, winding techniques has been motivated or sponsored by missile/space program.	Many companies doing filament winding for missile/space program also doing commercial filament winding. Capabilities developed through missile/space work used in making commercial products which include: air tanks for truck brake systems, automotive parts, tank cars, chemical vats and tanks, brassiere supports.
Chemical Milling		Chemical milling solution to problem involving forming thin aluminum rocket casing. Since inception it has been used extensively in space, missile, aircraft industry and has been refined considerably as result.	Prime commercial use of chemical milling has been in aircraft industry. Other commercial use limited to making auto trunk lids. Process quite versatile and significantly more commercial use expected.
High Energy Forming	High energy forming originated late 19th Century. Used for making doorknobs and spittoons. Process lay dormant until mid-1950's.	High energy forming adapted and refined by missile/space companies for shaping hard-to-form metals, making large forms and unusual shapes, and achieving close tolerances in forming of parts. Normally used where only small number of parts required. Typical applications include missile heads, missile fuselage sections, tube ends, tank ends.	Identified commercial use to date small but more expected. One interesting commercial application is forming stainless steel feed wheel for orange juice squeezer.
Solid State Bonding	Original impetus seems to have come from nuclear reactor field where solid state bonding used in cladding fuel elements.	Solid state bonding researched extensively as result of missile/space program. Process must be understood to keep metals from sticking together in space. Joint structure of solid state bond has properties approaching metals itself. Will join metals to non-metals. Because of two preceeding advantages, has application in fabricating foils for hypersonic vehicles--aircraft and winged re-entry.	Solid state bonding has non-missile/space use in cladding fuel elements for nuclear reactors (although this was an original use, experience gained on space work improved technique). Anticipated future uses include fabrication hydrafoils for boats and joining electronic components.
Miscellaneous	Missile/space needs stimulated use and improvement of clean rooms for manufacturing precision equipment; necessitated development of improved fluidized bed furnace; made feasible development of relatively inexpensive temperature chamber.		
MATERIALS			
Refractory Metals	Refractory metals primarily laboratory curiosities and alloying additives in 1940's. Some work done in utilizing refractory metals in 1950's for jet engines.	Need for high temperature metals for solid fuel rocket nozzles, energy convertors, ion or plasma propulsion systems, winged re-entry vehicles, recoverable boosters, etc., has stimulated much research on tungsten, molybdenum, columbium, and tantalum--most economical refractory metals.	Technology stemming from missile/space motivated research on refractory metals should be applicable to future aircraft engines, nuclear reactors, heat exchangers, other devices where higher efficiency can be obtained with higher operating temperature.

Exhibit A (Cont.)

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
Maraging Steels	Recently developed for commercial and aerospace applications.	Use in fabricating large rocket motor casings contributed to the knowledge of properties of Maraging steels. Missile/space program accelerated production of thin gages by making available research and testing facilities, personnel, and by purchasing thin gages for large pressure vessels, e.g., skin of solid propellant rockets.	Maraging steels used commercially where welding pre-machine pieces with little distortion or where welding full hardened pieces desired. Knowledge developed in missile/space work should be applicable to such application. Thin gages may find future application in tankage or in hydrafoils.
Physical Metallurgy	Basic research in area going on for number of years.	New and special demands on metals made by missile/space programs stimulated and fostered ideas for investigation into specific areas of physical metallurgy. Missile/space requirements also motivated expenditure of funds for basic research in physical metallurgy.	No specific commercial use of knowledge generated by this research identified. Most knowledge gained will be available to non-space sector and eventually will find commercial application in development of new alloys.
Superalloys	Development of superalloys coincided with evolution of gas turbine engine in aircraft industry. Aircraft industry supplied much motivation for research on superalloys.	Missile/space program provided some impetus to continued development and refinement of superalloys. For example, superalloys used as primary structural members on X-15, as shingles on Mercury re-entry capsule, and superalloy planned for use on Dyna-Soar.	Improved superalloys will probably find use similar to original aircraft use in gas turbine engines, e.g., turbine buckets, rotors, nozzles, guide vanes, combustion liners, after burners, and structural members.
Epoxy Resins	Epoxy resins discovered shortly after World War II by researchers in U. S. and Switzerland. Early use in airframe construction.	Additional applications of epoxy resins recognized as missile/space requirements materialized. More stringent requirements stimulated development of new formulations. Applications include protection of vehicle and launch pads from exhaust flames during launches; repair of structures at sub-zero temperatures; encapsulation of electronic components for missile/space systems. Several new formulations developed as result of missile/space needs.	Some formulations developed specifically for missile/space needs found commercial application. For example, epoxy resin that hardens at sub-zero temperatures finding commercial application in wintertime repair work.
Miscellaneous	Missile/space research has stimulated: improvement of commercially useful aluminum alloy; research and experimentation on pyrolitic graphite, an anisotropic refractory with commercial potential; development of line of dynamic materials testing equipment now being used commercially; improvement of commercial metal hose; development of honeycomb structural material used on boats, buildings, aircraft; origination of all metal insulation used in nuclear piles.		

Exhibit A (Cont.)

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
MEDICAL TECHNOLOGY		Effort to place man in space makes unique demands on human organism. It puts great importance on evaluating man's capabilities prior to space mission and in monitoring response to mission's stresses. Resources available for major space programs, e.g., the Mercury program, led to elaboration of known physical examination, evaluation techniques, development of new methodology. Physical performance monitoring requirements for space missions and advances in electronic miniaturization, reliability, telemetry have worked together to encourage innovations in medical electronics.	New techniques for comparative measurement of physical capability appear useful in judging physical aging and in determining damage from disease or accident. New examination procedures already in use, as are many electronic devices for measurement and monitoring.
RE-ENTRY SIMULATION--THE PLASMAJET	Theoretical foundations laid early 1920's. Word "plasma" first applied to ionized gas in 1928.	Missile/space field, with requirement for working with and testing high temperature materials for rocket nozzles, stimulated development of plasma generator. In addition, 6,000°F gas needed to produce high velocity air for re-entry simulation in hypersonic wind tunnels. This also stimulated development of plasma generator.	From missile/space work evolved commercial plasma torch which can provide stream of inert gas at temperatures high as 30,000°F--much hotter than can be achieved with chemical combustion. Torch used in cutting and welding. Also used to spray refractory materials or plastics on surfaces to protect from high temperatures and corrosive chemicals. Plasma gun spray coating will raise melting point of basic surface, increase abrasion resistance, produce corrosion and oxidation resistance.
TELEMETRY AND COMMUNICATIONS		Research being done and progress made in following areas: design of effective antennas; development of receivers which will amplify weak signals with minimum of self-induced noise, incorporating such devices as parametric amplifier or maser; emphasis on minimum size, weight and power consumption in transmitter and receiver development; application of transmitter and receiver modulation techniques in conjunction with information theory to get maximum reliability in noise environment; choice of optimum coding and decoding techniques to prevent accidental or unauthorized operation of remote control functions; alleviation of crowding of electromagnetic spectrum.	Problems researched for missile/space application have counterparts in non-missile/space military or commercial communications and telemetry. Particular stress given each problem area may vary but problem areas similar and transfer encouraged for this reason. Several examples of transfer identified. More expected.

Exhibit A (Cont.)

TECHNOLOGICAL AREA	GENERAL PRE-MISSILE/SPACE BACKGROUND	PREVALENT MISSILE/SPACE CONTRIBUTION	COMMERCIAL OR NON-MISSILE/SPACE APPLICATION OF MISSILE/SPACE CONTRIBUTION
VIBRATIONAL TESTING	Failure of World War II aircraft to perform properly due to vibration led to development of early vibrational test equipment.	Vibrational test equipment improved and refined because of more severe vibrational environment encountered in missile/space applications. Vibrational testing machines developed for missile/space and jet aircraft application generate non-sinusoidal wave forms as well as complex wave forms which cannot be expressed in simple mathematical terms. Equipment used to qualify gyros, relays, diodes, transistors, tubes, accelerometers, and other electronic, electrical, mechanical components before final use in missile or space system.	Equipment originating with space or missile work being made available for use in non-space commercial industries, e.g., automobile industry, to test merit of components and structures before large scale production run.
PACKAGING AND SHIPPING	Packaging of items for shipment not new.	Circumstances particularly acute in missile/space industry necessitated improvement in packaging and shipping containers and techniques. Components developed for missile/space field often have high value per pound and easily damaged. In addition, by time components have reached final application, they have been unpacked, handled and repacked many times. Two problems created: (1) probability of damage increased due to frequent handling, (2) constant packing and repacking significantly increases overall cost. Several containers, devices, techniques developed to help solve problem.	Identified packaging and shipping devices developed originally to meet missile/space needs transferred to commercial industry to meet similar packaging and shipping requirements.
MANAGEMENT AND CONTROL--PERT		PERT outgrowth of sheer complexity of Fleet Ballistic Missile, or Polaris, program. Development of PERT began February 1958 under auspices of Special projects Office, Department of Navy. Technique operational later in 1958 and used to help with evaluation of contractor and subcontractor scheduling in Polaris program. Approximately same time similar technique called Critical Path Method (CPM) developed by Remington Rand in conjunction with DuPont to schedule chemical plant construction. Since original use, PERT has spread rapidly throughout missile/space industry and has been expanded and refined.	PERT, CPM and combinations of two used commercially. Existence of PERT, its spectacular success on Polaris program, and use by government contractors probably accelerated diffusion of both PERT and CPM throughout industry. Latter may be more important contribution of PERT than PERT's direct use in commercial industry.

Exhibit B

TABULATION BY TYPE AND DEGREE OF IDENTIFIED MISSILE/SPACE CONTRIBUTION [1]

AREA OF TECHNOLOGY	DOMINANT TYPE(S) OF IDENTIFIED CONTRIBUTION						APPARENT DEGREE OF CONTRIBUTION			ANY PRESENT NON-SPACE COMMERCIAL CONTRIBUTION IDENTIFIED ?		
	Stimulation of Basic and Applied Research	Development of New Processes and Techniques	Improvement of Existing Products	Increased Materials and Equipment Availability	Development of New Products	Cost Reduction	Strong	Moderate	Slight	Yes	A Small Amount	Commercial Contribution All Potential
Instrumentation												
Resistance Strain Gages	X		X	X	X			X		X		
Infrared Instrumentation						X		X		X		
Pressure Measuring Equipment	X			X	X			X				X
Temperature Measuring Equipment			X		X			X		X		
Instrumentation Amplifiers			X	X					X			X
Electronic Components and Miscellaneous Systems												
Semiconductors	X		X		X	X		X		X		
Microsystems Electronics	X					X	X				X	
Thermoelectric Refrigeration			X						X		X	
Connectors, Cables, and Printed Circuits			X					X		X		
Display Systems					X			X		X		
Control Systems												
Inertial Guidance	X						X			X		
Electronic Computer Systems	X		X		X			X		X		
Power Sources												
Solar Cells	X					X		X		X		
Thermionic and Thermoelectric Energy Conversion	X						X				X	
Fuel Cells	X							X				X
Magnetohydrodynamics	X						X					X
Propulsion												
Cryogenics	X			X		X		X		X		
Fluid Transfer Systems			X	X		X		X		X		
Fabrication												
Filament Winding	X	X					X			X		
Chemical Milling	X	X					X			X		
High Energy Forming	X	X					X				X	
Solid State Bonding	X	X					X				X	
Materials												
Refractory Metals	X						X					X
Maraging Steels	X								X			X
Physical Metallurgy	X						NA[2]			NA[2]		
Superalloys	X								X			X
Epoxy Resins					X				X	X		
Medical Technology	X	X			X				X		X	
Re-Entry Simulation - The Plasma Jet	X				X		X			X		
Telemetry and Communications	X		X					X		X		
Vibrational Testing	X	X	X					X			X	
Packaging and Shipping					X			X		X		
Management and Control - PERT		X					X				X	

Notes: (1) Based on company statements and technological background summaries in Chapter VI. For more detailed information see Chapter VI.
(2) Not applicable. See information on Physical Metallurgy in Chapter VI.

Chapter II

INFORMATION FLOW

A secondary objective of this study was to provide insights into the flow of information contributing to commercial applications of missile/space related technology. The results of this inquiry are presented here.

A. SURVEY FINDINGS

"How did you acquire information on the space technology that went into your by-product?" was a question asked of firms whose by-products, items of contribution, or technological transfers are described in Chapter VI.* The replies stressed the importance of such technological information sources as "close customer contact" and "own R & D experience." In answer to another question, the same firms suggested the flow of such information could be accelerated by "improved indexing, abstracting, and reporting services" and "easier access and prompter declassification." Tabulated answers follow:

Methods of Obtaining Missile/Space Technology Mentioned by Firms Reporting Cases of Transfer

Close customer contact	35
Own R & D experience	32
Technical and trade journals	15
NASA and Military Specifications and/or laboratory data	14
Meetings, committees, and symposia	11
Literature search	7
Suppliers	5
ASTIA	3
Outside laboratories (other than NASA or military)	2
Patents	1
NASA directed information from NASA research contractor	1

* The data were obtained by the mailing of 3,507 questionnaires, and from brief attention during interviews with 189 firms, government agencies, and other organizations. See Chapter V, "Methodology." No data were available on many of the items of contribution, and no exhaustive effort was made to trace back the technological inputs through all of those participating in the development of any items. Many of the responses were from executives or marketing people, rather than technological specialists or others with direct knowledge of the circumstances. However, replies in varying degrees of detail were received from 48 firms whose items of contribution are included in Chapter VI, and from 31 firms which did <u>not</u> report transfers or contributions. There was no differentiation between information sources and channels of communication; that is, many of the sources given were obviously not primary or original sources of information. Very little statistical significance can be attributed to the distribution of replies, but the rankings may be of interest. (Some replies indicated several methods of obtaining missile/space technology.)

The stress given "close customer contact" is worth attention because about half of these replies evidently did not refer to this as a source of technology but as a source of requirements information. Some were prime contractor requirements, some were government customer requirements, some were commercial customer requirements. In each of these cases, however, the respondent evidently considered market requirements information sufficiently important to volunteer it as an information input to his transfer of technology. In other cases, "close customer contact" evidently referred to opportunities to learn of primary or missile/space applications which could then be developed to secondary or commercial applications.

The next most important category of answer was "own R & D experience." This appears to reflect instances where a firm's own knowledge of missile/space technology and primary applications of this technology helped it either 1) to develop commercial applications, or 2) to transfer the primary application or product into a secondary market as a by-product. Instances of these are detailed in Chapter VI under sections titled "Electronic Components and Miscellaneous Systems" and "Electronic Computer Systems."

The most important information input in both of these categories appears to have been information about a primary application.

The related question asked on the same questionnaire was: "What could be done to improve the flow to you of usable information about space technology?" The distribution of these replies follows:

Suggestions for Improved Information Flow, From Firms in Which Transfers Have Occurred

Improved coverage, quality, and speed of indexing, abstracting, and reporting services	20
Easier access (e.g., to ASTIA) and prompter declassification of research results	14
Present information flow OK	10
Limit the quantity of information, improve the quality	4
More technical seminars on specific topics	3
Customers (government agencies, prime contractors) should work more closely with specialist firms	2
Better information on component requirements	2
A directory of innovations might encourage licensing and production	1
Government patent policy discourages divulgence of information	1
Use existing information channels	1

Some of these answers were evidently commenting on the flow of information for primary use, as well as information for secondary or commercial use.

This question on improved flow of usable information was also answered by a number of firms which did not report transfers or by-products. Many of these firms voiced a desire to participate in missile/space manufacturing, and many were small businesses. These responses follow:

Suggestions for Improved Information Flow From Firms Which Have Not Experienced Transfer	
Easier access and prompter reporting of research results	11
Present information flow OK	10
Make available better information on requirements for items and components used in space programs (mostly firms wishing to sell to space customers)	8
Want more information, but don't know what sources or channels should be	7
Make it easier for small or specialized firms or outsider firms to get space business or get space information	4
Direct publications by NASA of summaries of innovations	4
Improve coverage, quality, and speed of indexing, abstracting, and reporting services	3
Hold regional seminars on space innovations	3
Publish more technical papers	3
Customers should inform themselves better of capabilities of small firms	2

It is interesting to note that, in both tabulations of responses to this question, while the majority of firms indicated a desire for improvement in flow of information, a substantial number indicated satisfaction with the present flow.

B. IMPLICATIONS AND RECOMMENDATION

Few firm conclusions can be drawn about the flow of missile/space technology to commercial applications people from either the responses to the Denver Research Institute questionnaire or from existing research on the diffusion of technology.* Both may offer suggestions and insights, however, for anyone concerned with building up the rate of commercial application of missile/space technology.

Except in those instances where the same organizational unit generates the missile/space technology and applies this technology in products it sells, it seems possible that there are relatively few cases of direct communication of technology from original innovator to final user or applier. Rather, mediators such as R & D personnel may

* Recent research on the diffusion of technology and innovation is reviewed in Chapter VII. An effort is made to relate it to our findings, and a number of questions are raised for further research on the information requirements for the commercial application of missile/space technology.

(or may not) filter, evaluate, and relay it. To the extent this is true of the primary user firm, it is probably even more true of the secondary or by-product user.

Instead of simple, direct communication links between missile/space innovators and commercial applications users, the vehicle for transferring technology usually seems to be a complex process of information diffusion. Major improvements in this communications system(s) must generally be designed in the context of the whole diffusion process, and not just as improvements in information dissemination or reception. Therefore, basic research appears needed to better define and understand the diffusion process, and the systems through which the process works.

Chapter III

IDENTIFICATION AND MEASUREMENT

This chapter presents additional information on the nature of the technological transfers from missile/space programs to commercial applications and provides an insight into the difficulty of formulating conclusions about the current economic significance of these transfers.

Section A, "Identification," supplements the methodology discussion in Chapter V by describing the manifold problems involved in achieving the primary task of this study: identifying specific examples of missile/space transfer. Furthermore, Section A describes one of the most important limitations inherent in measuring the economic significance of this transfer: much of it cannot be identified.

Section B, "Measurement," summarizes the general problem of measuring the economic impact of any inventive and innovative activity and discusses the additional difficulties imposed when the problem is narrowed to the measurement of technological transfer or by-product impact.

A. IDENTIFICATION

Assignment of Credit

The most important identification problems arose from the fact, sometimes overlooked, that invention and innovation are continuing processes. Likewise, product development goes on continually in most firms and usually is subject to many influences rather than a single influence such as the missile/space program. As a consequence, many firms contacted replied in effect: "Our company has no space by-products, but rather our space products are the result of the products which we have been selling to our commercial customers, and this is the reverse of what you are expecting to find in your study."

Of course, we recognized before starting the study that many missile/space products were built on earlier commercial products and a broad pre-space technological base. We expected that products would be found which had originated in commercial developments years ago and had subsequently been improved to meet missile/space requirements, these improvements in turn being incorporated back into the non-space products, resulting in better commercial products. As it turned out, cases of this type were more prevalent than any other; the space contribution was simply an improved version of an earlier established product. A problem developed, however, in explaining to the organizations contacted that, for the purposes of our study, this type of product improvement was considered a valid transfer or by-product. How many such by-products existed when the contacts were made but were not reported because of differences in interpretation is not known.

The question of whether space or non-space use came first, or whether significant improvements were incorporated into an existing product because of space experience, has been the cause of much confusion in past discussions of by-products. Some items have been widely publicized as being space by-products which actually are not, largely because of this problem. A short description of one such case may serve to illustrate the problem.

Pyroceram brand glass-ceramics. A line of cooking utensils, called Corning Ware, has been developed by Corning Glass Works from one of a family of new materials. This new class of materials--named Pyroceram brand glass-ceramics--was developed in the mid-1950's by Corning's Research and Development Division. By inducing crystals to grow in a glass body, Corning researchers transformed it into a glass-ceramic article, hard and heat-resistant. By controlling the crystal growth and glass composition, literally thousands of kinds of glass-ceramics could be created. Further development by the Consumer Products Division established that one of these glass-ceramics could resist breakage from heat better than the heat-resistant cooking glass invented in 1915 and utilized by Corning in the manufacture of many of its Pyrex brand products. In addition, the Pyroceram brand glass-ceramic products looked like expensive china. Therefore, the Corning Ware line was created. In 1959, its first full year on the market, some $15 million of Corning Ware products were sold.

In the meantime, Corning's New Products Division was also working on one of the glass-ceramic families. It was found that this glass-ceramic's excellent thermal and mechanical properties, plus the fact that radar waves passed through it easily, made it a good material for guided missile nosecones. The formula was used to make missile nosecones now used by U. S. and foreign defense forces. The company states that these Pyroceram brand radomes came about as a consequence of the development of this glass-ceramic material without reference to its possible use in missile or space applications. The confusion over the development apparently arose when the company began to advertise some of its commercial products, such as Corning Ware, as being associated with the missile nosecones. The company tied the space and non-space applications of the Pyroceram brand materials together in its advertisements to emphasize, for its commercial market, that these glass-ceramic materials were so new that they had found application in the space program. Apparently as a result, Pyroceram brand glass-ceramics have frequently been cited in articles dealing with space "fall-out" as a by-product.

This example of a commercial product whose origin has been associated erroneously with the space program indicates some of the difficulties associated with attributing credit to missile/space programs versus commercial endeavors.

Dual Motivation for Product Development

Several instances are reported in Chapter VI of products which were developed by firms with their own funds, or on a cost-sharing basis with the government, in anticipation of being able to tap both the missile/space market and the commercial market. While we included these as examples of transfer within the study definition when it appeared the development would not have taken place in the absence of the space portion of total estimated demand, the problem was splitting credit between the two sectors. This facet is discussed further in Section B, "Measurement."

Information Withheld or Unavailable

There were several reasons, most of them entirely valid, why companies did not want to or could not reveal information which was necessary to the identification process. They are:

Proprietary information. When the by-product to be marketed was in a highly competitive field, companies were obviously reluctant to release information unless the timing and content of this report meshed with their planning for the product under consideration.

Premature releases. Several companies had items which were in the sometimes lengthy process of development or market planning and which they did not want publicized prematurely in the event the product failed to live up to expectations. Unfortunately, the reverse of this was also true. Some companies were happy to receive any publicity they could, although it was fairly obvious that no definite commercial marketing plans existed and commercial sales were, at best, very dubious.

Security. A substantial number of firms reported that they produced to government specifications for prime contractors and thus did not know the end uses of their products. In some cases, companies tried to ascertain the end uses but were denied the information because of military security requirements.

Information unknown. A related problem, frequently mentioned, is that many suppliers do not know the end use of their product (for other than security reasons). Several metals companies, for example, commented on their role in furnishing raw materials and semi-fabricated products, one stating that it had "not found any very definite instances where by-products have been developed, undoubtedly due to the nature of our participation simply as a basic materials supplier." Another reply, typical of several received from electronic component producers: "Difficult to determine which applications are for space use and which for commercial computers." Transfers may have resulted from missile/space work done by firms such as these but it is impossible for them to say with certainty.

Potential patent problems. Some companies were unable to release information because they were in the process of filing patent applications and could not afford to compromise their position with a premature disclosure of product descriptions.

Incomplete Information

In many cases it was necessary to rely for information on the memories of individuals concerned with the particular development within the contacted organizations. This led to many problems: often the individuals did not remember details pertinent to this study; in other cases the individuals who had been associated with a development were unavailable or had left the company. Within the limitations of this project, it did not appear feasible to attempt to undertake the major task of tracking down missing pieces of information which were not readily available, nor was it feasible in all cases to ask the companies concerned to do this. Therefore, it was necessary either to rely on the information available or to omit the item under consideration.

Other Problems

One person seldom possessed all the information desired. This necessitated several interviews in each organization or, in some cases, resulted in incomplete information. Also, it was difficult to identify the best contact within the different organizations. Finally, it was often necessary to know enough about a company's operations to be able to suggest some examples of possible transfer. With the large and varied number of contacts made, it was impossible to do this in every case.

In conclusion, we believe it is not feasible to identify a sufficient portion of the universe of individual items of transfer to meet the minimum requirements of the first task of quantitative impact measurement--identifying that which is to be measured.

B. MEASUREMENT

At the outset of this project, thought was given to the possibility of future research designed to measure the economic impact of commercial contribution from missile/space related technology. Many individuals contacted expressed the hope that quantitative measures of both present and probable future impact could be developed. Unfortunately such measures appear to be almost impossible to construct at this time. Economic impact measurement was not an objective of this study; however, sufficient insight was gained in the course of identifying technological transfer to assess the problems involved.

Measurement of general inventive activity is itself a formidable problem which has not been solved to anyone's satisfaction. Moving from a measure of this activity to a measure of economic impact greatly increases the problem. Focusing the task to measurement of the economic impact of missile/space technological transfer reduces few problems and adds many. In this section, problems common to the measurement of general inventive activity and impact will be discussed, drawing largely on what others have written. Following this, the special problems of measuring transfer impact will be discussed, relying primarily on experience gained during this study.

According to Kuznets, the general problem in measuring inventive activity is that no good methods for measuring inventive input or output exist.[1] Measures of input--dollars spent on research or numbers of people engaged in research--are not adequate because large variations exist in the creativity and productivity of different inventors; furthermore, inventive activity is unpredictable. Data are more available on inventive output--patent statistics, patent office files, and occasional lists of inventions published in the literature--but these data have not been converted into efficient measures of inventive output.

Sanders differs with Kuznets in the relative availability and usefulness of available inventive input and output data. But he concludes that, "None of the measures used to date is satisfactory even as a crude measure of inventiveness as such or inventive activity."[2]

Even if a measure of the output of inventive activity did exist, it would be subject to interpretation and would not be a measure of economic impact. Suppose (very hypothetically) that some figures were available for inventive output for the past year, or past several years. The figures would not tell: 1) what secondary and tertiary sales had been generated by the invention--a multiplier effect, and 2) what items have been made obsolete, or less useful, by the new inventions--the netting-out effect. A notable example illustrating these two effects is the invention of the automobile. While sales of both the petroleum and steel industries were given great impetus, sales of wagon wheels and buggy whips diminished. The problem, of course, is that any element of product improvement tends to change the market structures of all industries related to that product. Not only is the product changed, but the frame of reference is changed, and trying to measure the impact of product improvement is analogous to measuring a dimension with an elastic ruler.

The one exception is pointed out by Winter in a report prepared by the former Operations Research Office of the Johns Hopkins University entitled, <u>Defense Spending and the U. S. Economy</u>:

> Where research yields its rewards in the first of these ways alone [cost reduction in the production of products], the measurement problems can be rendered manageable by the use of physical production coefficients in conjunction with standard dollar valuations of input and output. This procedure... results in a precise figure for the cost saving per unit, which, when multiplied by the number of units produced, yields the dollar return which is to be compared with the cost of the research.
>
> In the absence of population growth and capital accumulation, the estimation of the return to research for the economy as a whole would be no more difficult in principle than the task in the case of the individual firm... reasoned assumptions as to the patterns of change of the productivity of labor and capital could be made on independent grounds and the residual change in productivity attributed to the research effort.

The report goes on to say,

> The really serious problems of measurement arise when the returns to research contain an element of product improvement... in contrast to the situation where cost reduction alone is involved and the physical constancy of the final product provides a basis for comparison of the "before" picture with the "after" picture. [3]

The measurement difficulties for invention in general are not alleviated, but compounded, when the measurement of transfer impact, as contrasted with general inventive impact, is undertaken.

Identification

Obviously, a first step in measurement is identification of that which is to be measured. But as Section A of this chapter points out, mere identification of concrete examples of transfer is difficult due to the problems of whom to credit for a development, security restrictions, proprietary information, fear of premature publicity, incomplete historical information, inability to make contact with the proper individuals, and possible patent problems.

Classification

Once an item of contribution has been identified, many additional difficulties bar economic impact measurement. These difficulties can be better understood if the types of contribution are categorized, for the method of measurement and the problems involved seem to vary with the type and amount of missile/space contribution made to the item. The classification proposed in Chapter I is convenient for this purpose. Three types of contribution drawn from this classification will serve to illustrate the measurement problems: cost reduction, product improvement, and stimulation of basic and applied research.

Impact measurement of the first type of contribution mentioned, cost reduction, seems the easiest of all and would, in all probability, follow the method proposed by the Operations Research Office outlined above.

Product improvement poses a more serious problem. Suppose that a potentiometer, for example, has been improved 15 percent in reliability and 30 percent in accuracy as a result of research done to meet missile/space specifications. It would be unfair to attribute all the commercial sales of the improved product to the missile/space program, but a contribution has been made. What part of the total sales should be taken as a measure of missile/space contribution? 10 percent? 20 percent? 30 percent?

Stimulation of basic and applied research is the least tangible and most difficult to measure of all. The ultimate impact of this type of contribution will occur in the form of new products, processes, materials, etc.; but this type of contribution is several steps removed from the product-process-materials level. In most cases, it is too early to know even a small fraction of the products that ultimately will be generated by this research. If some products have resulted and can be identified, it is difficult even to guess what portion of the ideas, knowledge, and technology embodied in the product came from missile/space motivated research. Product generation frequently represents a synthesis of knowledge originating from many sources and it is quite likely that the persons responsible for generating products under these circumstances would have, at best, only a fuzzy idea of which knowledge truly represented missile/space contributions. That most missile/space research is grounded on pre-missile/space scientific knowledge further compounds the difficulties. Thus there is no apparent way of determining the proportionate contribution of missile/space research to an item coming from this type of transfer, and hence no way of allocating gross sales--or any other measure of economic impact--as to missile/space versus non-missile/space contribution.

Types of Measure

In the examples above, sales has been mentioned as a measure of economic impact. However, other quantities might also be measured: employment, profitability, or effect on gross national product. The quantity chosen would depend partially on whether impact is to be measured with reference to the firm, the industry, or the economy.

Sales. If sales is chosen as a measure of output several problems arise, some of which have been partially discussed. First, merely getting sales data can be difficult since some organizations consider these data proprietary and are not willing to release them. Of all the possible measures of impact, however, sales would probably be the easiest to secure; the real problem comes not in getting the data, but in interpreting them. To use the total sales of an item of transfer as a measure of impact could present a very distorted picture if the item contains only a small degree of missile/space contribution. Unfortunately, for measurement purposes, much of the total missile/space transfer takes place in the form of partial and intangible contributions to commercial products. How, then, should sales be divided to present a true picture?

The problem becomes more confusing when the components or materials manufacturer does not know what percentage of the sales of his product goes to missile/space versus non-missile/space use. For example, an alloy may have both of these uses and may incorporate some space contribution. If the percent of non-space sales is not known, how can the gross sales of the product be allocated without doing costly market research?

Using sales as a measure becomes still more confusing when a price reduction is brought about by volume production for the missile/space program because dollar sales may actually decrease though productivity has gone up.

Employment. Generation of employment might well be used as a measure of impact and could be very meaningful in view of today's high rate of unemployment. Unfortunately it is subject to the same difficulties as sales--and more. The increased difficulty comes in obtaining employment data; direct and indirect employments tabulated by product are figures not normally kept and to get them would take more digging at the level of the firm than to get sales data. Once the data are secured, however, employment is subject to the same interpretation problem as sales. Total employment generated by an item of transfer is not a meaningful figure. Again, some basis must be found for taking a reasonable percentage of the total in accord with the significance of the missile/space contribution and in accord with the percentage of non-space market. Last, technology tends to increase productivity, thereby increasing or decreasing employment depending upon a number of factors, making the interpretation of the employment measure almost hopeless.

Profitability or Effect on GNP. Profitability also poses all the problems of measuring sales and generates some new problems of its own. Of course, sales must be measured before profitability can be determined. In addition, the sales of a product must be compared with the cost of that product (including cost of research) to determine profitability. But cost of research is a very difficult quantity to allocate to any one product due to factors mentioned before: the uncertainty of invention, the widely varying inventive productivity of individuals, the market structure change caused by product improvement, and the variable time lag in which research yields its returns. Nor does it appear feasible to measure the effects of transfers on gross national product, due to aforementioned factors: chiefly, the multiplier and netting-out effects brought about by market structure change.

In conclusion, reasonably accurate measurement of the economic impact of missile/space transfer appears to be infeasible at this time. To quote Winter again in Defense Spending and the U. S. Economy:

> In short, it appears that the study of the benefits to the civilian economy provided by military research can depend only in minor degree, if at all, upon existing sources of information. Neither at the individual firm level, nor at any level of aggregation, do reliable data exist upon the return on research activities in general, let alone upon the portion of these returns which may be a by-product of military research efforts. And any empirical work in the field will inevitably run into all of the logical and methodological problems which are responsible for the present lack of information on these topics. [4]

Even though measurement is not presently feasible, the commercial sector of the economy has received both tangible and intangible benefits from missile/space research as demonstrated by the examples described in Chapter VI. To argue now that this benefit is negligible, as some have, or tremendous, as others have, is futile because of all the problems discussed in this chapter. The existence of the many items of transfer identified and described in Chapter VI, at this early stage in the missile/space programs, combined with the knowledge that the transfer process takes time, justifies the expectation of more in the future.

Chapter IV

TIME LAG

This chapter discusses the unknown and variable time interval between the inception of missile/space technology and its commercial application. Not only is time lag an important part of this process, or any inventive process, which should be recognized and analyzed, but it is also a factor which further complicates the identification of examples of transfer and the measurement of their impact.

Section A, "Background," presents relevant information on the role time lag plays in the inventive process and relates this to commercial application of missile/space developments.

Section B, "Duration," discusses factors which affect the length of time lag. Section C presents conclusions.

A. BACKGROUND

Throughout the study, comments were made in both interview and questionnaire reply on the importance of "time lag." For example:

> We have had many important by-products in the commercial field as the result of past war and defense contracts, and I have confidence that, similarly, there will be important by-products of the U. S. space program. I would expect that the time lag involved would vary with the complexity of the program.

or:

> There has not been enough time since NASA got underway in 1959--or even since the inception of the Air Force missile program--for too many by-products to be forthcoming. We expect much more in the future.

S. Colum Gilfillan in his book, The Sociology of Invention, states that inventions normally progress slowly in the period prior to their practical application and that inventions coming before "their time" remain undeveloped and practically useless. [1]

The term "time lag" as used by individuals contacted was never defined explicitly but was generally used to refer to the hiatus between inception of a missile/space technological development and its commercialization. Since invention, innovation, product development, and marketing are overlapping and continuing processes, it is impossible to identify the beginning or end of time lag.* Both the date of inception and date of commercialization of a product are rather arbitrary. How far back in time can the inception of a product be traced? Does commercialization refer to first commercial sales or to

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* Invention implies discovery or development of something new and innovation implies the introduction and application of inventions to practical use. Careful distinctions between the two terms are not normally made in the literature nor were attempts made to do so in this report. In practice, a given item frequently can embrace both concepts, thus making careful distinctions somewhat academic. (See Reference 2 in the "Introduction.")

commercial success? The point is that exact definition or quantification of time lag is not so important as recognition that time lag is an integral part of the inventive and technological transfer processes.

Some figures exist on time lag duration, however. Gilfillan studied a group of 19 inventions selected in 1913 by vote of Scientific American readership as the most useful inventions introduced in the preceding quarter century.[2] He found that the geometric mean interval between the year the invention was first proposed and the year of the first working model or patent was 176 years. He also found: geometric mean between first machine or patent to first commercial use--24 years; first commercial use to commercial success--14 years; commercial success to important use--12 years.

Two other lists were prepared by Gilfillan. Of the 75 or so most important inventions of the period 1900-1930, the median time lag between first working model or patent and first commercial success was 33 years. The other list, covering 209 of the 500 most important non-military inventions of the period 1787 - 1935, showed a median interval of 37 years from first serious work to commercial success. (This figure applies to only those inventions started before 1900.)[2]

In our study, five to ten years was quoted most frequently as the period required to develop and market an item incorporating technology transferred from missile/space programs. There are two important differences between Gilfillan's time lag and ours, however. First, Gilfillan studied the total invention from first thought to fruition, while we studied just the secondary or by-product aspects of an invention. Second, Gilfillan studied only important inventions, while we studied all types, including many relatively unimportant innovations. In addition, many of our identified transfers are not inventions, e.g., cost reductions and product improvements.

Nevertheless, a significant time lag exists between missile/space development and commercial application. Good illustrations of the time lag factor include descriptions in Chapter VI: 1) Marquardt (Section F) in which time lag from first requirement for a materials testing machine for the missile program to finished commercial testing machine was six years; 2) Amphenol-Borg (Section B) in which time lag from first contract to develop a new series of connectors for the Air Force to first commercial sales of the finished connector line was about seven years; and 3) Minneapolis-Honeywell (Section C) in which time lag from first automatic pilot to first work on adaptive flight control for missiles was fourteen years, and time lag from first missile work to first commercial sales of an adaptive autopilot for light aircraft was six years. An especially lucid example of by-product time lag was given us by the Garrett Corporation.* The total time lag from the start of its work on high-speed rotating machinery for the aircraft industry to the commercial success of a product incorporating the technology resulting from this work--a turbo charger for diesel and gasoline engines--was 17 years. Had this product been conceived in the missile or space program, it would not be in existence yet.

B. DURATION

A time lag barrier exists, therefore, to the commercial application of missile/space innovations, and a few figures have been presented to indicate its significance.

* In this case, the by-product evolved from aircraft work and therefore is not included in Chapter VI.

However, a quantitative estimate of time lag is meaningless unless viewed in light of those factors which affect its duration. Unfortunately, those factors are not well understood. Some of the companies interviewed or contacted by questionnaire set forth possible determinants of time lag duration, based upon their own experience. These can be summarized as follows:

1. Non-missile/space utilization of missile/space developments or concepts is necessarily a secondary objective. Many concerns participating in the missile/space program have been too concerned with fulfilling their primary objective in that program to give much attention to possible commercial application of knowledge gained.

2. The technological content of most missile/space products is <u>many years ahead</u> of that found in commercial or industrial products. Introducing such products before their time into an industrial or commercial system is analogous to using a piledriver to pound a nail.

3. Most missile/space products, because of their high technological content, are expensive relative to their industrial or commercial counterparts. For example, an extremely reliable resistor may be an absolute necessity in the Minuteman program but a luxury in an industrial computer. Initially such a product may receive only specialized industrial use, but as more units are used the price will come down and as the price comes down more units will be used. Eventually the product may find widespread non-space use but this process of "sliding down the cost curve" takes time.

4. A corollary to the latter two points is that missile/space products or developments representing small improvements transfer into the commercial economy faster than those representing major innovations.

5. The intensity of the effort put forth to commercialize a missile/space development can affect the time lag. This effort can be divided into three parts: (a) adapting the product or development to commercial or industrial use from its present missile/space form; (b) producing it; and (c) actually selling the product. But, many missile/space oriented firms are not organized to do these things, thus increasing the time lag.

Each of these factors indicates, as would be expected, that profitability is an important key to time lag. Edwin Mansfield, Associate Professor of Economics at Carnegie Institute of Technology, doing work on a related subject, has come to a similar conclusion. Basically, he concerned himself with the questions: 1) How long do firms in a given industry take in adopting a technological innovation, once it has been adopted by one firm? 2) What factors determine the length of time taken? After studying 12 important innovations in four major industries, he reached these conclusions: 1) Diffusion of a new technique is slow; except in a few cases, ten years or longer elapsed before all major firms in an industry had introduced the innovation in question. 2) Higher rates of diffusion are associated with more profitable, less risky innovations. Determinants of risk would include size of capital expenditure and number of other firms which had already adopted the innovation. 3) Although no statistically significant correlations were observed, the rate of diffusion apparently increases when the innovation does not replace durable equipment, when an industry's output is growing, and when the innovation is introduced at a later date in time, i.e., innovations introduced in the 1900's tended to diffuse more slowly than those introduced in the 1950's.[3]

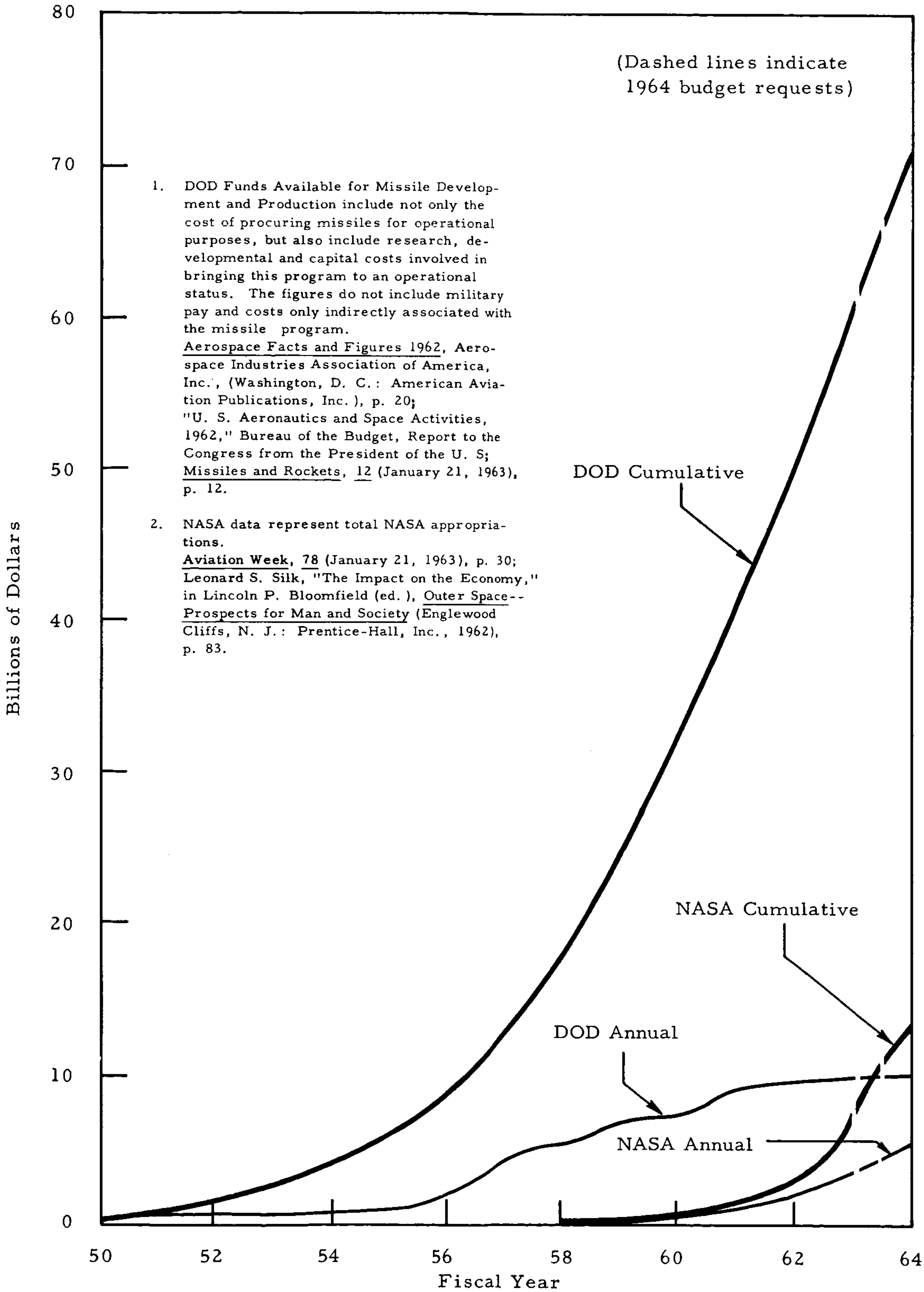
While Mansfield was dealing with a different time lag, the time lag between the first and last company's adoption of an innovation, his work underlines the importance of time lag and of profitability in accelerating commercial application.

C. CONCLUSIONS

We can observe that, because of the relative newness of both the missile and space programs, commercial products incorporating missile/space contributions are just beginning to appear. The Air Force missile program did not really get under way until the mid-1950's; NASA was not established until 1958. Figure 1 presents estimates of the time and money involved in missile/space programs to date. Taking time lag into consideration, it would be unreasonable to expect a large proportion of the transfers which eventually will occur to have occurred at this time.

We can also observe that while there has been some investigation of the factors which influence time lag a better understanding is needed. Questions which appear to need further research include: What part does technological content play in increasing time lag? How important is marketing in decreasing time lag? Is the time lag decreasing with the increasing store of technology, as Mansfield suggests? Are certain industries more apt to adopt innovations than others? Are certain institutional structures more receptive to innovations than others? If obtainable, answers to these and other questions pertaining to time lag may permit interested organizations to take positive action in accelerating the commercial application of missile/space technology.

FIGURE 1. MISSILE/SPACE SPENDING
Department of Defense[1] and National Aeronautics and Space Administration[2] Annual and Cumulative



Chapter V

METHODOLOGY

The proposal leading to the NASA grant sponsoring this study of missile/space technological transfer was prepared in the Spring of 1961. Sufficient background research was performed then to indicate that difficulties would be encountered in identifying and documenting instances of transfer. Therefore, it was proposed that various points of entry into the problem be explored on a trial and error basis, with the major research emphasis placed on those avenues which were subsequently determined to be the most promising.

Most of the anticipated difficulties materialized after the study got underway in December 1961, plus a few more. Many of these have already been described in Chapter III. In general, the number of transfers or items of contribution exceeded by a substantial margin what had been anticipated. However, there were fewer clear-cut examples than expected of commercial products which had resulted almost wholly from missile/space contributions. Instead, the majority of the ingredients of most commercial products, which had received impetus from missile/space programs, came from non-missile/space sources. This complicated the identification process, as is discussed in Chapter III.

The approach used in the study is outlined in the following sections. Development of the study framework is discussed first, followed by descriptions of the central research effort and alternative points of entry which were attempted, including brief evaluations of each. The discussion concludes with a few remarks about the verification procedure.

A. DEVELOPING THE FRAMEWORK

A literature search revealed little information of direct value to the major objective of identifying missile/space transfers to the non-missile/space sectors of the economy. The few sources which did attribute specific items to the missile/space programs later proved too inaccurate to be of much value. Considerable useful background material on inventive activity and communication was found (see References and Bibliography).

Early in the study, interviews were conducted with a variety of persons selected on the basis of related experience. Included were individuals in NASA, various private and public economic research groups, trade magazine staffs, the National Science Foundation, the Library of Congress, the staff of the House Committee on Science and Astronautics, and the Office of Technical Services, U. S. Department of Commerce. In addition, the professional staff of the Denver Research Institute was canvassed for preliminary ideas and transfer leads.

On the basis of these preliminary steps, a definition of "missile/space" was formulated for the study purposes, and preliminary criteria were developed to govern what qualified as a missile/space transfer. The initial interviews were very helpful in anticipating data collection difficulties, in formulating classes or types of transfers to be sought, and in suggesting sources of related information.

It became apparent at this time that major reliance would probably have to be placed on direct contact with individual organizations, especially industrial firms, to produce useful results. Therefore, an interview guide was prepared which also could be used as a mail questionnaire. This was pre-tested in interviews with about a dozen firms, modified, and submitted to and approved by the Bureau of the Budget via NASA, as required. A copy of the final questionnaire is included at the end of this chapter.

B. CENTRAL RESEARCH EFFORT

Various methods of transfer identification were initiated during the study. Some continued until identification efforts were concluded in October 1962; others were dropped when they failed to produce results. Personal contact and mail questionnaires proved more effective than the less direct methods discussed later, and field work was concentrated in these areas after February 1962.

Selected for personal contact were organizations which appeared most likely to have or know about transfers. In all, 369 individuals in 189 organizations were interviewed. These organizations fell into the following categories:

142	industrial firms
21	government agencies and installations
7	universities and university research organizations
8	independent research organizations
11	miscellaneous
189	total

A letter, enclosing a questionnaire, to the president or head of each organization preceded visits in almost all cases. Regarding industrial firms, the positions held by persons interviewed varied widely, the initial interviewee usually having been chosen by the president's office. Where appropriate, two or more persons per firm were seen. Persons most often interviewed were technical and sales vice presidents, marketing and product managers, product development and product planning personnel, laboratory managers, and patent attorneys. On the average, personnel associated with product development, product planning, and marketing were the most productive contacts for the information sought. Seldom, however, did one individual have all desired details, necessitating additional interviews and/or follow-up correspondence or telephone calls. Although there were notable exceptions, research personnel were often too remote from marketing functions to be helpful, and public relations personnel were too far removed from both technical and marketing functions to supply details required.

A number of firms contacted had established special groups whose purpose was to find and exploit transfer ideas from the main stream of their research and development efforts, as described in Chapter VIII. Usually, the transfer identification task was relatively straightforward in such firms since most details could be furnished by these special groups.

The personal contact method yielded the most usable information per contact and in total--resulting in 111 of the 185 instances of transfer or contribution included in Chapter VI, or 60 percent of the total. Firms in the aerospace industry, on the average, were especially fruitful sources of information, probably because the transfer frequently took place within the firm and could be identified more readily. Government, university, and independent research laboratories were handicapped by separation from commercial markets and consequently possessed limited application knowledge. Information obtained from trade associations was disappointing, again probably due to market separation.

The mail questionnaire route was used extensively to broaden the coverage of organizations. In June and July 1962, questionnaires were mailed to 3,507 organizations. Replies were requested even though the recipient could report no instances of transfer. Replies were received from 988 organizations, a 28.2 percent response; no follow-up of non-respondents was made. Only a small proportion of the replies, 5.7 percent, produced descriptions of transfer included in Chapter VI.

The mailing list was compiled from several sources:

Number of Organizations	Type of Organization	Source
1,947	Company	Poor's Register of Directors and Executives, 1962. Selection procedure: 115 four digit S.I.C. codes were selected from the Standard Industrial Classification Manual by eliminating those believed least likely to have experienced missile/space transfer; Poor's Register contained 14,168 companies in these 115 codes, of which every sixth was chosen, using a table of random numbers to choose the first one in each category; after elimination of duplications with other lists, the total of 1,947 firms resulted from this process.
*397	Company	Fortune magazine's listing of "500 Largest U. S. Industrial Corporations."
600	Company	Compiled from miscellaneous sources.
*167	Company	Electronic Industries Association membership.
* 58	Company	Aerospace Industries Association membership.
26	University	Those having the largest dollar volume of government contracts in the missile/space field.
30	Trade Association	Those judged most likely to have had contact with the missile/space programs.
7	Government Agency	Included research and patent offices of U. S. Army, Navy and Air Force, plus patent office of A. E. C.
275	Company	Leads gathered from a variety of sources such as magazine advertisements, articles, exhibits, and individuals. Special paragraphs were inserted into many of these letters referring to the lead and requesting further information.
3,507	Total	

An effort was made to construct a portion of the mailing list to permit some statistical analysis of the returns. However, the usable data were too limited and scattered for such an analysis to be statistically meaningful.

* Duplications with firms on other lists were omitted from these lists.

Of the 185 examples included in Chapter VI, 74 (40 percent) were derived by this method.

C. OTHER IDENTIFICATION EFFORTS

Trade journals, magazines, and newspapers. Early in the study, a selection was made of trade journals, magazines, and newspapers considered most likely sources of transfer leads. These were monitored throughout the information-gathering portion of the study: Air Force and Space Digest, Astronautics, Aviation Week, Business Week, Data, Electrical Design News, Electronic News, Industrial Research, International Science and Technology, Medical Electronic News, Missiles and Rockets, Science Trends, Scientific American, Space Aeronautics, Wall Street Journal, and Western Electronic News.

The new product sections, regular features included in a number of these periodicals, were watched carefully at first for leads but they did not prove fruitful. A few good leads were found in articles and advertisements. The major value of this effort was in providing background information.

Government Information Services. Several periodic government publications designed to disseminate technical report descriptions were monitored early in the study: Scientific and Technical Aerospace Reports (successor to Technical Publications Announcements), a semi-monthly publication of the National Aeronautics and Space Administration; Technical Abstracts Bulletin, published by the Armed Services Technical Information Agency (ASTIA); and reports prepared by the Office of Technical Services, U. S. Department of Commerce. Few leads were obtained from these sources because possible commercial applications were not described. Considerable time was required to monitor them and this activity was discontinued after several months. Later, a few specific and helpful individual reports were obtained from these agencies which were brought to our attention by other sources.

NASA. Certain of the records in the patent office of NASA pertaining to waivers for invention rights were examined and the petitioners were contacted by letter to ascertain whether any of the inventions were being worked on a non-space basis. No instances of transfer were identified by this method, although some may result from further development work in process. In addition, contacts were made with the NASA Research Centers. Five were visited, and the remaining five were contacted by letter. A few transfers were identified by this process and are included in Chapter VI. At the time these contacts were made, the NASA Office of Technology Utilization was in the early stages of formulating a program to identify developments of potential commercial use in the Centers. Therefore, our timing was premature to capitalize on this identification medium.

Conferences and Conventions. Several conferences, which appeared to be of possible help to the project effort, were attended in conjunction with interviewing trips: Annual Public Conference, The Patent, Trademark and Copyright Foundation of the George Washington University, Washington, D. C.; "Managing the Technological Revolution," 32nd National Business Conference, Harvard Business School, Boston, Massachusetts; and the National Aeronautics and Space Administration Second National Conference on the Peaceful Uses of Space, Seattle, Washington. In addition, the Annual Conference of the American Association for the Advancement of Science, Denver, Colorado, was attended. These provided helpful background information.

Two conventions, Western Space Age Industries convention in San Francisco and the Institute of Radio Engineers convention in New York City, were attended by Institute personnel. Although each convention displayed many new products which appeared likely to have missile/space program connection, transfer identification was difficult because the personnel manning display booths, generally speaking, were not well versed on the history of a product's development. In addition, the number of products displayed was too large for comprehensive coverage even if the information had been available.

D. VERIFICATION PROCEDURE

Methods used to obtain details surrounding the reported instances of transfer were described at the beginning of this chapter. Difficulties encountered in determining whether a reported transfer met the study qualifications are outlined in Chapter III.

At the beginning of the project, it was agreed that information supplied by a responsible official of an organization would be sufficient verification of a reported transfer. Upon completion of our field work, however, it became apparent that additional information would be desirable to place the individual instances of transfer in perspective. That is, by grouping similar items and preceding their descriptions with a background or historical and state-of-the-art discussion, the relative significance of missile/space contributions to their development would be more clear. Preparation of this background material was a major task but it greatly aided the qualitative analysis of the transfers and produced a better understanding of the diffusion process.

Approved: Bureau of Budget No. 104-6201
Expiration Date December 1962

QUESTIONNAIRE

A STUDY OF THE COMMERCIAL BY-PRODUCTS OF THE U.S. ROCKET AND SPACE PROGRAMS

EXPLANATION

Every large research and development effort supported by the United States government (such as World War II military research) has produced substantial technological advances useful to private industry. There has usually been a long time lag, however, before the impact is felt by industry.

The National Aeronautics and Space Administration would like to speed up the process of introducing applicable space technology to non-space industry. New product development, based on rapid technological advances, is one of the best ways for American industry to compete with foreign industry. Part of the problem is to identify space by-products that are already used or produced by industry and to find out how the ideas migrated from the space program. The University of Denver Research Institute, financed by a grant from NASA, is investigating this part of the problem.

Details of the information we seek are outlined below. At the end of each section of descriptive material, we have asked general questions. We have done this, rather than use a questionnaire with blanks, to give you maximum latitude for reply.

INFORMATION DESIRED

In answering, please try to comment on each of the numbered questions for each of your by-products. Photographs or descriptive material would be helpful. **Please send your reply to: Industrial Economic Division, Denver Research Institute, University of Denver, Denver 10, Colorado.**

What do we mean by a space "by-product"? A space by-product, first, has a non-space use. Second, it is a device, material, process, system or technique which has resulted or received impetus from the rocket and space effort.

Question: 1. *What by-product(s) does your firm utilize or produce, and briefly, how is it described?*

A space by-product may be based on:

—An entirely new discovery.

—An invention or innovation.

—An improvement of an existing device, material, etc.

—An old discovery or device made commercially feasible by large-scale production for the rocket and space market.

—Any other development which exists because of the space effort.

Questions: 2. *In which category does your by-product fit?*

3. *What is the history of your by-product's development? (In other words, what pre-space development did your by-product come from, and what part did the rocket and space effort play in its further development?)*

A space by-product may be related to the space effort in many ways:

—It may have been developed to go on a particular rocket or space vehicle.

—It may have been developed to supplement the production or launching of a vehicle (ground support equipment, test equipment).

—It may have been developed to sell to the missile and space market in general (off the shelf items).

Questions: 4. *How is your by-product related to the space program; what are its rocket or space uses?*

5. *What are its present non-space applications? Future?*

Development of a space by-product may be funded in several ways, for example:

—Funded in-house.

—Funded by NASA.

—Funded by the Department of Defense or other federal agency.

—Funded by another firm.

Question: 6. *How was development of your by-product funded?*

Better information regarding the channels through which space technology moves will permit wider use of this technology.

Questions: 7. *How did you acquire information on the space technology that went into your by-product?*

8. *What could be done to improve the flow to you of useable information about space technology?*

Any additional remarks or comments would be appreciated.

Confidential* Treatment

We shall respect your wishes to keep any information that you give us confidential. If you desire your reply to be treated confidentially, *please so state* in your reply. If so stated, we shall follow this procedure:

> Before including any information you have marked confidential in our report to NASA, we shall submit our write-up to you. You may then make any corrections before approving its use. In *no* case will we include confidential information in the report until we have your written permission.

*Business confidential, not to be confused with the security classification "confidential."

Chapter VI

EXAMPLES OF TECHNOLOGICAL TRANSFER

A variety of contributions, mostly in the form of transfers of missile/space technology to the non-missile/space sector of the nation's economy, were identified in the course of this study. As was described in Chapter V, identification techniques included interviews and the use of a questionnaire. An explanation of the information search procedure, with its multiple problems and inferences, was detailed in Chapters III and V.

The purpose of this chapter is to present in an organized fashion specific examples of these contributions as revealed by some of the companies and government agencies cooperating in the study. The term "by-product," while prominently used in the wording of the study grant, is used only with discretion throughout this report for reasons thoroughly explained in Chapter I. Briefly, however, the term was often found to be inadequate or misleading in attempting to identify the much broader concepts of missile/space "contribution" or "technological transfer."

It should be made clear at the outset that the example descriptions in this chapter of the various forms of missile/space contribution were authorized and, for the most part, supplied by the responding agencies and companies. However, each major category of contribution, e.g., Instrumentation, is preceded by background information which places the examples themselves in some perspective. Such backgrounds were, for the most part, prepared by the Denver Research Institute staff.

To qualify as a missile/space program contribution and consequently for inclusion in this chapter as an example, the described product or development must: 1) have received some impetus from the missile/space program, and 2) have either experienced a non-missile/space use or have a reasonable potential for such use. It was found that all contributions could be classified into one or more of six categories which are set forth in some detail in Chapter I.

Even though the term "missile/space" is sometimes cumbersome when used to identify a described contribution, it has significant connotations in the context of this study. Without embarking on a lengthy discourse in semantics, suffice it to say that a "missile/space" contribution refers to a device, system, technique, material, etc., derived from or given impetus by a missile program, a space program, or both. For example, a technological or product derivative from the Mercury program would be referred to as a "space" contribution while one from the Titan program would be a "missile" contribution. However, since both types of programs are often involved in a single contribution, or since it is convenient to refer to both missile and space programs simultaneously, the term "missile/space" is often used.

Furthermore, "missile/space" is interpreted to involve a vehicle that is not dependent on aerodynamic principles for support. However, this restriction was broadly interpreted to permit inclusion in the examples of derivatives from the X-15 and the Navaho missile, systems having both rocket and aerodynamic characteristics.

Before dismissing a discussion of terminology, it might be appropriate to distinguish between the terms "non-missile/space" (particularly cumbersome) and "commercial." Certain contributions of the missile/space effort are "commercial" in the sense that they help create technologies or specific, marketable products of benefit to civilian industry and ultimately to the private consumer. In addition, however, there are also examples of adaptation of missile/space-founded technology to non-missile/space military or other governmental applications and these fall within the scope of this study. For this reason, "non-missile/space" is a more flexible concept than "commercial." However, when the missile/space derivative was obviously commercial in the sense just described, the term "commercial" was employed.

To embrace the full impact of missile/space contributions, it was necessary to draw upon entire missile systems and space systems for examples. For instance, transfers originating in ground support equipment development were included since the development of ground support equipment was a missile or a space requirement. The same reasoning applied to other aspects of missile/space systems, such as production techniques and management systems. In fact, one section is devoted to "Management and Control--PERT."

Communications and weather satellite programs were specifically excluded from the examples, except as R & D on system components themselves might have resulted in commercial applications of discoveries, innovations, and the like. The omission of these systems was specified by the sponsor.

Research and development efforts on missile/space programs have been sponsored principally on a contract basis using government funds from three main agencies: NASA, the Department of Defense, and the Atomic Energy Commission. However, there are included in this chapter examples of missile/space oriented contributions from developments that were originated and funded not by the government but by private industry and independent research organizations. As it was the existence of the missile/space market that encouraged these non-governmental R & D efforts, it was appropriate that they be included. Also included was missile/space R & D performed by various federal laboratories. From whatever source, contributions from research motivated by the missile/space programs were included.

Within this frame of reference then, the content of this chapter has several inherent limitations which should be noted:

1. The items of contribution presented can be considered neither a complete listing, i.e., a census, nor representative in the statistical sense of what may actually exist. For reasons explained in Chapters III and V, it is doubtful that a complete listing could be compiled, regardless of study effort. While an attempt was made to construct a sample of industrial firms to permit generalizations of certain study results, such results have no statistical reliability, for reasons also explained in Chapter V.

2. The contributions presented here represent less than half of the items reported by the organizations contacted or tentatively identified from other sources. It was impossible in certain cases to obtain sufficient details in order to be reasonably certain the items qualified as contributions. In other cases, it was apparent that the reporting organizations had not fully understood what qualified an item as a contribution. In still other cases, it was necessary to make somewhat arbitrary eliminations of items which appeared too doubtful to warrant follow-through. Therefore, an unknown number of prospective items of contribution reported or otherwise tentatively identified during the course of the study were undoubtedly omitted.

A study of this kind is sometimes an easy receptacle for inaccurate information from responding organizations. Research people often have little control over individuals who finally disseminate R & D results, particularly in large organizations. This may lead to the identification of a by-product or item of contribution from the missile/space effort which does not truly qualify under study criteria. Also, historical origins of an item of contribution are relatively unimportant to most organizations and hence seldom recorded.

To reduce the probability of inaccuracies, two steps were taken: a) Appropriate technical staff members of Denver Research Institute reviewed each example description, adding more descriptive material where feasible from literature searches and personal knowledge. b) That part of the descriptive material based on the responding organization's submission was referred to the organization for review.

3. Descriptions of the examples of contributions are not intended to be in any sense all-inclusive. Many important contributions to the development of pre-missile/ space technologies are omitted as their inclusion could fill volumes; besides, they are not within the scope of the study. However, background data preceding each "case" description serves somewhat to fill this information vacuum.

Within all of these limitations, selected examples of missile/space contribution follow--the items with similar missile/space functions and therefore similar technological characteristics are grouped together under a major category heading. Categorization of this kind is always difficult and subject to various interpretations so that some of the groupings may appear quite arbitrary. Technological backgrounds and experiences of individual Denver Research Institute staff members dictated some of the groupings as might be expected. Examples which overlapped several categories were placed where the missile/space contribution seemed the most significant.

It might be advisable to refer to the two exhibits at the end of Chapter I before examining the example descriptions themselves: Exhibit A, "Summary of Missile/Space Contribution by Technological Area" and Exhibit B, "Tabulation by Type and Degree of Identified Missile/Space Contribution."

Presentation of the examples follows this format:

A. TITLE OF BROAD TECHNOLOGICAL AREA

1. Title of Technological Sub-Area

This is followed by a background summary of that area of technology--the when, who, why and how of the particular discipline or sub-discipline.

Name and Location of Responding Organization
Which Reported the Contribution

title of item to which missile/ space programs made contribution — Description of the contribution as supplied by the responding organization. When additional material is supplied by Denver Research Institute, it is separated from the example description by a series of four asterisks. Deviations from this format have been made to provide for exceptions. However, the description of the contribution example as supplied by the responding organization always immediately follows its name. Examples of contribution not readily identifiable with a specific technological grouping are contained in sections designated "Miscellaneous."

A. INSTRUMENTATION

1. Resistance Strain Gages

A strain gage is normally used to detect and measure displacement resulting from stress, or, as a transducer, to indicate force, torque, acceleration, linear or angular displacement, flow or pressure. The origin of the strain gage dates back about 300 years to Robert Hooke who discovered that, within limits, stress (force) is proportional to strain (mechanical deformation). Later, Robert Young (1773-1829) provided a quantitative relationship between stress and strain in the form of the Modulus of Elasticity. Poisson (1781-1840) extended the laws of elasticity by discovering a relationship--Poisson's Ratio--which made possible the extension of the study of strain to three dimensions.[1]

In 1856, Lord Kelvin discovered that certain metals, when subjected to strain, undergo a change in electrical resistance. Application of this to the measurement of strain, however, was not made until the late 1930's when gages were built by mounting wires on a frame whose two parts could move with relation to each other, thereby changing the tension in the wire. Increasing the tension would elongate the wire, diminishing its cross-sectional area in accord with Poisson's Ratio, thereby increasing its resistance (Strain also influences the availability and mobility of electrons in the wire, but this effect is not completely understood.) Strain, then, produces an increase in resistance in most metals--although some show a decrease.[1]

In the late 1930's, the mechanical frame was eliminated by cementing the sensing element directly to the surface on which strain was to be measured. Soon afterwards, strain gages were made easier to use by premounting them on thin paper or plastic carriers.

Sensitivity of these frameless, or bonded, strain gages was increased with the substitutions of foil or evaporated metal films for the wire. Such gages, first available about ten years ago, have undergone extensive development since. These are easily made in a great variety of sizes and patterns for measuring various forms of distortion. In the past few years, gages utilizing semiconductors have been built and undoubtedly will find broad use in the future for determining very small displacements, as they are much more sensitive than their metallic counterparts.

A major effect of space research will be to expand the sphere of application of the strain gage. Missile airframes and engines face temperatures far in excess of present strain gage limits. Gages are now needed to measure displacement at temperatures varying from 4°K to 1000°F; soon gages for use up to 2000°F will be in demand.[2] At high temperatures, the electrical resistance of the gage material changes; gage grid, carrier and bonding cement undergo thermal expansion; electrical insulating property of the cement changes; strain sensitivity of the grid material changes; gage oxidizes or corrodes more rapidly; and finally, many cements decompose.[3] Organic cement and epoxies, for example, lose dielectric and mechanical strength above 500°F. Phosphate and ceramic cements are useful to 1000°F; above 1000°F weldable strain gages must be used. (See the description which follows on Weldable Strain Gages, Microdot, Inc. in this section.)

Another trend in recent years has been toward improved readout equipment. Readout equipment has progressed from single channel devices, operated by a skilled technician, to miniaturized, multichannel equipment which can monitor and automatically process the signal from many strain gages at once. Much impetus has come from the missile/space field where this type of equipment is a necessity. (See the descriptions below of Indicating Millivolt Potentiometer, Ames Research Center and the two examples from B & F Instruments, Inc.)

Examples of missile/space impetus to commercial applications of strain gages follow.

Baldwin-Lima-Hamilton Corporation
Electronics Division
Waltham, Massachusetts

strain gages and transducers improved through missile work

The primary activities of the Electronics Division are the development and manufacture of devices and systems for precision measurement and control. Much of the division's work is the development of products and processes based on the SR-4(R) strain gage, developed in the late 1930's by E. E. Simmons of the California Institute of Technology and Arthur C. Ruge of MIT. Four basic types of strain gage are currently being produced by the division--the SR-4 Bonded Wire, the SR-4 Bonded Foil, the BLH Semiconductor and the Strainline Photoelastic. Within these, 300 standard models are made, and custom models are available. Strain gage and temperature measuring products manufactured by this division are used in all phases of the missile program to determine safe stress levels, stresses at exceedingly high temperatures on nosecones, and stresses in rocket casings before, during and after fueling.

The division also manufactures transducers based on strain gages to measure force, pressure, and torque. Its line of precision force transducers is used in the space effort to measure missile weight during fueling, to measure missile thrust during static missile firing, and to locate missile centers of gravity and main thrust vectors. Its line of precision pressure transducers is used to measure rocket chamber pressures, fuel line pressures, and other pressures vital to the successful operation of missiles.

In order to keep pace with the needs of the space effort, the company is continually developing new and more precise force and pressure transducers. As such devices are developed, they are also applied to the company's commercial activities. As an example, BLH can now offer more accurate, more stable, and more repeatable force transducers with capacities from ten pounds to six million pounds for commercial weighing--as used throughout industry. More precise pressure transducers are also applied to commercial industry.

Many of the products developed for the missile/space industry were improvements of products originally developed for the commercial field. Improved performance characteristics for missile/space are naturally reapplied to the commercial industries for which they were originally developed.

A Western Regional Strain Gage Committee organizes meetings twice a year between BLH and companies using their strain gages. The meetings give BLH an opportunity to tell of new advances in strain gages and related products and to learn of customers' specific needs. The meetings have been held twice a year for the last four years; about fifteen companies attended the last meeting.

The Boeing Company
Associated Products Division
Seattle, Washington

miniature displacement vibrometer

(potential)

This transducer was developed for wind tunnel testing in Boeing's missile, space, and aircraft programs. The primary use of the device has been the measurement of structural deflections excited by complex vibrations. The alternative--using accelerometers and integrating twice to get displacement--requires more equipment and is not as accurate on displacement or phasing measurements.

The sensitive element of this transducer is a strain gage; therefore, the output signal is directly proportional to the amplitude of vibration to which it is subjected. Furthermore, the transducer is well suited to high temperature operation (500° to 900°F). Without modification, the unit can be calibrated to transduce low frequency and steady state acceleration.

Boeing estimates that production costs are comparable to, or lower than, acceleration transducers, depending on accuracy, quality, and size. Total cost could be appreciably less in many instances because of simpler, less specialized support equipment. Low cost and small size are two of the transducer's most important advantages.

Boeing anticipates that this instrument can be used in structural testing, as in turbine engines or automobiles. This product is currently in the process of being licensed by Boeing.

Microdot Inc.
South Pasadena, California

weldable strain gage

Although strain gages have existed in several forms for many years prior to the space age, they were limited in that they had to be cemented with some form of glue or epoxy to the surface to be measured. This method of attaching strain gages proved unsatisfactory on high Mach number vehicles or missiles. Therefore, strain gage technology was advanced by a weldable strain gage developed for aircraft and missile/space applications by Microdot. For example, it was used on the X-15 and its predecessors. This gage provides a means for making either static or dynamic measurements of pressure, force, and acceleration, at temperatures ranging to 750°F (static) and 1500°F (dynamic). It consists of a one-piece etched wire filament in a swaged stainless steel tube. The filament is surrounded by tightly packed metallic oxide insulation. The gage can be welded to most ferrous and non-ferrous metals, including aluminum, magnesium, thorium, titanium, and lithium.

A later model of the same strain gage has leads which are brought through a stainless steel tube fused to the outer tube of the strain gage and subjected to a helium leak detection test to assure that the unit is hermetically sealed.

Non-space applications of the weldable strain gage include: measurement of piling strength on the St. Lawrence Seaway; measurement of strength of atomic submarine hulls; measurement of internal pressure of tanks of corrosive chemicals; and applications inside reactor cores at Los Alamos by the AEC.

Lockheed Electronics Company
Plainfield, New Jersey

palladium silver alloy

(potential)

Lockheed Electronics Company discovered a palladium-silver alloy that has the lowest temperature coefficients of electrical resistance over extreme temperature ranges of any known material. The discovery was the result of the firm's effort under a Department of Defense research contract to find materials suitable for accurate measurements at very high temperatures, e. g., strain gages employing palladium on re-entry vehicles.

* * * *

Although the use for this development seems limited, an alloy with these properties appears to have potential application in many types of non-space scientific instrumentation where it is necessary to avoid temperature effects.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California

indicating millivolt potentiometer

(potential)

NASA's Ames Research Center uses resistance strain gages extensively in its wind tunnel work. The IMP was devised to fulfill a need to measure the outputs from resistance strain gage transducers with an instrument that is simple to operate. It is intended for use with steady DC signals. Adjustable DC power is provided for excitation of the transducers. Convenient controls allow the setting of sensitivity and "zero" output level over wide ranges. The output is digitized by means of an indicator dial.

The IMP is a self-balancing servo-amplifier system that compares the external unknown signal with an automatically adjusted internal voltage so as to "null" the difference between them. The servo motion positions the indicator on a ± 1000 count dial to yield the digital reading. (A potentiometer whose wiper position varies with the indicator is also available to yield an analog high-level voltage output.)

The IMP sensitivity is continuously adjustable from below 0. 8 microvolts/ct. to 60 microvolts/ct. Its accuracy is ± 1 count or 0. 1 percent of full scale. Provisions have been made for compensation of thermoelectric potentials developed in the transducer and internal to the IMP.

In addition to its use with strain gages, the IMP may also be used to indicate the signal output of potentiometric transducers, resistance thermometers, and thermocouples.

So far, this device has only been manufactured under contract let by Ames Research Center to fill its own needs. However, Ames feels that the IMP has several advantages to offer commercial industry. The internal power supply, internal temperature compensation, high sensitivity, and availability of room and torque for the servo-system are features which are not usually available on other potentiometers.

B & F Instruments, Inc.
Philadelphia, Pennsylvania

Ten years ago B & F Instruments got its start with a standard line of input conditioning and bridge balance units. These were capable of operating from batteries or power supplies. Impetus from the various aircraft, missile, and space applications during the past decade has enabled the firm to develop its equipment in a number of directions simultaneously. Customer demands have placed emphasis on such needs as versatility, sophistication, complete automation, subminiaturization, and flexibility.

Most of the company's non-space developments have been achieved through fixed cost production contracts with NASA, the Department of Defense, and other federal agencies and their major contractors. The cost of final development and packaging of the item for its industrial use is usually amortized over the actual production contracts for the non-space applications.

<u>input conditioning equipment</u>

One example of this by-product development is the company's strain gage and transducer input conditioning equipment. In non-space applications, this input conditioning equipment has been applied to data acquisition control and monitoring in many industries. It conditions the output of transducers and prepares the output for entry into acquisition or control systems. Process industries such as glass, paper, and synthetic fibers are becoming more familiar with the strain gage and its uses.

<u>strain and thermocouple plotters</u>

Another example is B & F's multichannel strain plotters and thermocouple plotters. These instruments are used to prepare individual plots of strain versus load or temperature versus time for a number of variables. The automobile industry as well as other industries utilize most of these products for structural analysis in much the same manner that they were used by the early flight testers. Specific examples of non-space applications of these devices include: the structures laboratories of various universities have been purchasing these plotters to run stress-strain curves on various materials; manufacturers of large equipment, such as earth-moving vehicles, have been using them to prove out their designs; and road builders have been using the plotting equipment to determine long-term concrete creep.

2. <u>Infrared Instrumentation</u>

Infrared radiation is a form of electromagnetic radiation produced by any warm or hot object. Its wavelength is shorter than a radio wave but longer than visible light. "Infra" is from the Latin "beyond," so infrared means "beyond the red."

Infrared studies date from about 1800 when Sir William Herschel investigated this portion of the electromagnetic spectrum. Little was done in the ensuing thirty years, primarily because of a lack of suitable apparatus. Following this period a limited amount of activity took place as a result of the development of the thermopile detector. Between 1880 and 1900 great advances were made in the understanding of this spectral region and its relation to the total electromagnetic spectrum. From 1900 to about 1920, technical and scientific progress was rapid. Technological progress in the generation of shorter and shorter radio waves, on the one hand, and the detection of longer infrared waves, on the other, closed the gap between the two forms of electromagnetic radiation. In the same period, the existence of characteristic absorption and emission spectra of elements and compounds in the infrared region was discovered. This made possible the identification of complex organic materials, as well as an understanding of their molecular structure.[4]

In the period 1920-1940 solid state, infrared, photoconductive detectors were introduced and developed. The increased sensitivity of these materials permitted more sophisticated research programs and rapidly expanded the use of infrared methods in chemistry and pyrometry.[4]

Although the theory involved in infrared spectroscopy has been understood for some time, the widespread use of this technology has a fairly recent history. This is due both to the recognition of this branch of science as a powerful analytical tool and to the usefulness of infrared in weapons, space, and military surveillance. The impetus given infrared research by World War II has been continued by the needs of the missile/space program. Commercially available applications have resulted, ranging from rapid-scanning monochromators, useful in the study of rapid chemical reactions, to detection devices and photographic equipment.

Heat seeking guidance systems, utilized in the Sidewinder missile, have employed extremely sensitive detection devices and means to accurately measure and control infrared parameters. Therefore, missile work can be partially credited with the R & D instrumental in producing such equipment. Of more significance, however, is the quality and quantity of instrumentation required for missile/space systems, necessitating more refined, rapid production techniques. New production methods have reduced the cost of infrared devices, making available a range of devices with various characteristics that can be employed in commercial systems.

Examples of commercial infrared systems which have received this kind of missile/space impetus follow.

Infrared Industries, Inc.
Waltham, Massachusetts

The nation's space and rocket programs have built on and contributed to knowledge in the field of infrared technology. As a result, today there are products in being utilizing infrared technology which probably would not otherwise have existed. In many cases, the cost of a commercial product would have been prohibitive if the rocket and space programs had not provided a market large enough to permit mass production. Some of the new products which have been developed around the experience gained from rocket and space programs are as follows:

<u>Astro-phone</u> This is a telephone-like communications system based on the same infrared principles that are used in the guidance system of the Navy's Sidewinder missile and in Army and Navy signaling. Two identical instruments, each about the size of a home movie camera, powered by flashlight batteries, transmit line-of-sight messages on an infrared beam.

Each unit contains both the transmitter and receiver. The transmitter consists of a microphone, a voice-to-infrared converter, and an infrared source (ordinary flashlight bulb). The receiver is made up of an optical system with infrared filters, an infrared-to-voice converter, an amplifier and an ear-phone. The system has a range of several hundred yards when the units are aimed directly at each other.

The system was first marketed commercially in October 1960, under the name "Infraphone," to the transportation and construction industries, and public safety workers. During the Christmas season of 1961 the system was marketed as a toy under the name "Astro-phone."

<u>infrared rifle and range</u> Another toy based on principles quite similar to those of the Astro-phone system is the Crack Shot rifle and range. A pulse of infrared energy is emitted by the rifle when the trigger is pulled. The target is simply an infrared receiver, moving or stationary, which records hits by triggering a valve.

<u>Infrabeam</u> The Infrabeam is a photoelectric control device used for door automation; machine control; area surveillance; conveyor control; materials handling, inspection, and sorting; and liquid level control. Development of the Infrabeam is based on knowledge gained from the company's participation in the Sidewinder guidance program and on cheaper infrared components.

This device avoids many of the problems of light interference often associated with photoelectric controls. Optical filters selectively transmit only infrared radiation which is modulated or coded by the transmitter. The receiver is attuned to the same modulation and infrared frequency, and thereby is protected against saturation by visible light.

The transmitter and receiver are in two separate, detachable units with no electrical interconnection. Each unit is approximately 6 × 5 × 7 inches and is adjustable to operate either through reflection of the projected beam from an object or interruption of a direct beam by the object.

<u>Eagle "I" traffic detector</u> This device is quite similar to the Infrabeam. It is a vehicle detector which produces modulated infrared energy and projects it as a curtain across the vehicle lane. It can be used in either traffic control or counting vehicles.

Modulated infrared energy is directed through a Fresnel (spreader) lens forming a curtain of coded infrared energy. The self-contained receiver is also directed at the vehicle lane and is actuated by infrared energy reflected from vehicles as they pass through the curtain. The entire unit--projector, receiver and amplifier--weighs about 35 pounds and may be mounted over a traffic lane or from a side angle. The traffic detector has been approved by the U. S. Bureau of Public Roads and was first marketed in 1961.

Minneapolis-Honeywell Regulator Company
Heiland Division
Denver, Colorado

Traffitrol vehicle detector

Traffitrol is a vehicle counting or control device which employs infrared for detection purposes. It evolved largely through the use of several components, notably an infrared detector cell, supplied by companies whose research in the field of infrared rocket and missile trackers created products useful for non-space applications. Traffitrol is a compact unit which can be mounted on existing poles or any convenient structure. Its operation is not affected by stray radiation and will not interfere with radio signals. Traffitrol detectors are being installed in many major cities in the United States as well as abroad. Development costs were funded by the company.

3. Pressure Measuring Equipment

The first method of measuring static pressure which was capable of scientific accuracy probably dates back to 1643 when the mercury barometer was used by Torricelli. The mercury barometer measures external pressure by the height of a column of mercury supported by that pressure. This method still serves as a primary standard. There was little need for measuring time-varying (dynamic) pressures until the advent of the steam engine, and its needs were satisfied by the relatively crude steam engine indicator giving the pressure-volume diagram and thus a measure of "indicated" power output. With the continued development of heat engines, the need increased for accurate dynamic pressure measurements, leading primarily, in the pre-space era, to studies of internal combustion engine characteristics, ballistics, and explosives.

The requirements of combustion and other propulsion kinetics research efforts have increased in recent years. This has given impetus to the development of methods for measuring dynamic pressure. Prior to this time, the development and use of such equipment was primarily in the field of internal combustion engine research, where significant progress was made. Now, however, these earlier requirements are being exceeded by demands of high velocity shock wave deterioration, and other aerothermodynamic studies. The basic objective remains the same--to determine the true magnitude of pressure of the physical phenomena under study and to record its pattern of change with time.[5]

Many types of devices are now available for static and dynamic pressure measurements. In most of these devices, the pressure to be measured produces a mechanical strain or displacement which is then converted to an electrical signal. The basic strain elements most used have been the Bourdon tube, in either circular or twisted form, the single diaphragm in countless versions, the double diaphragm or capsule, the bellows and, to some extent, the strain tube. Methods used for converting displacement to electrical output have been based upon many forms of wire strain gages, potentiometers with movable wipers, capacitance variation, reluctance variation, stretched wire frequency variation, and "null" methods in which servomechanisms are used to achieve a force balance. The piezoelectric principle (the interaction of mechanical or electrical stress-strain variables in a medium such as quartz) neatly combines both strain element and signal conversion in one piece.

Space and missile requirements have greatly accelerated the development of improved pressure transducers and associated equipment. The pressure range and frequency response characteristics of previously existing types were inadequate. Much improvement was needed to insure reliable pressure measurement under severe environmental conditions such as high and low extremes of temperature, corrosive fluids and atmospheres, high levels of shock and vibration, and the possibility of severe pressure overloads. Additional requirements, for some units at least, were the ability to function properly under space-vacuum conditions, to provide relatively high level output for telemetry systems, to have maximum possible reliability, and to be of minimum weight and volume.

One of the critical problems facing the developers of rocket engines is combustion instability. In studying this and other problems it is necessary to have accurate dynamic pressure measurements at frequencies up to 50 KC, well beyond the range of all but the most exotic systems as recently as 1958.[6]

Although considerable improvement could be expected by further refinement and modification of existing designs, this needed order-of-magnitude improvement, it was apparent, would have to come from some other approach.

Two different approaches have produced great improvements in the transducer field. One exploits the use of electronic compensation to overcome the physical limitation of the basic transducer; the other is based on the use of semiconductor materials which exhibit the phenomenon of piezoresistance.

A breakthrough was reported early in 1958 by Dr. F. F. Liu and T. W. Berwin of Rocketdyne.[7] The "DADEE" system (Dynamic Analog Differential Equation Equalizer) utilizes operational amplifiers in a configuration determined by the differential equation describing the dynamic response of the physical transducer. By this means, "ringing" is substantially eliminated and pressure transients having rise times on the order of one microsecond have been recorded. The DADEE system automatically and instantaneously compensates for the dynamic characteristics of the transducer during any transient or steady-state measurement. (See the Rocketdyne description which follows this section.)

Piezoresistive transducers are now available commercially, have much higher gage factors, and much less error response due to shock and vibration than previously available strain gage pressure transducers.[8] These are suitable for in-flight service as well as ground test work.

Space research requirements have also stimulated development of better methods for measuring low pressures, particularly for altitude measurement and wind tunnel instrumentation. The emphasis in the latter field is on devices which are adaptable to a high degree of automation of data gathering systems.

There has been considerable carry-over from the development of pressure transducers for missile requirements to improving the standards and increasing the knowledge of the whole field of pressure measurement. In addition, the missile/space industry has created a quality market for sophisticated dynamic pressure devices, making them generally and economically available for other scientific and engineering uses. In a very real sense, in view of pre-space and present day sales volume, the requirements of the missile/space program may be said essentially to have created a large part of the present pressure transducer industry.

Examples of missile/space impetus to non-space applications of pressure measuring devices follow.

North American Aviation, Inc.
Rocketdyne Division
Canoga Park, California

DADEE
dynamic
analog
differential
equation
equilizer

(potential)

This device was developed as a result of specific needs which Rocketdyne experienced in the course of its missile and space programs. It provides a means to recover, observe, and record--in real-time--accurate analog data which would otherwise be masked and distorted by the limitations of the measuring system. It virtually eliminates the undesirable "ringing" which results from the excitation of the transducer at or near the natural resonant frequency.

Rocketdyne licensed this device to the Data Instruments Division of Telecomputing Corporation about four years ago. It is being marketed by Telecomputing under the name "Tranqualizer" which is a contraction for transducer-equalizer. Initial marketing revealed the demand to be limited for the product in its original form and at its original cost. Therefore, a product development program was initiated by Telecomputing to adapt the device to a larger market. This development was completed in the summer of 1962 and resulted in several changes. The physical size of the device was reduced, which lowered the manufacturing cost and made it more competitive on a cost basis. The unit, originally using vacuum tubes, was completely transistorized. The frequency range of response was lowered to ten to 20,000 cycles per second, suitable for a majority of its potential applications. A second solid state unit available soon will have a frequency response approaching 500 KC.

The sales volume of this unit has been small to date, and confined entirely to the aerospace industry. However, Telecomputing anticipates that with the improved device, it will be able to broaden its uses to include non-space applications.

* * * *

It is believed that this device can be used wherever a problem exists in extending the physical response of a transducer. This would be especially true where it is necessary to make high-speed measurements, such as fast change of temperature or acceleration. Specific examples might include internal combustion research and gas turbine engine development.

Servomechanisms, Inc.
El Segundo, California

pressure
measuring
device

(potential)

Servomechanisms produces rocketsondes used in meteorological instrumentation. The company is engaged in supplying various temperature and pressure measurement devices for use by government agencies and their prime contractors.

The company's first contract required instrumentation that would measure pressures at altitudes between 80,000 and 250,000 feet where common barometric sensing devices are not applicable. These pressure measurement devices are an integral part of the nosecone of a rocket which is sent aloft into the atmosphere to determine atmospheric conditions prior to a missile launch. These devices are lifted, via a rocket, to an altitude of approximately 100 to 125 miles. After reaching that altitude, they are parachuted to earth. Meteorological information is telemetered to the earth while these devices are being lofted into the atmosphere as well as during their return to earth.

Since this initial contract, various other pressure and temperature measurement devices have been developed, both with company funds and under government sponsorship. The company feels that there is strong by-product potential for these devices for use by the Weather Bureau to determine more accurate world-wide weather forecasting. Attempts to market them for this purpose are currently in progress. The company's first pressure measurement device, known as a Glow Discharge Densitometer, was developed with company funds.

* * * *

This device does not meet the requirements of a "non-space" application set forth in this report, and hence should not be considered a missile/space contribution within the report context. It is included here, however, to illustrate a potential cross-over from one space application to another.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California

<u>slack diaphragm differential pressure transducer</u>

(potential)

The Ames slack diaphragm differential pressure transducer, which has been built and used in relatively large quantities in ranges from one psi to 30 psi, was developed to replace the liquid manometer pressure measurement systems widely used in wind tunnel research. Liquid manometers are not compatible with high-speed data recording and electronic data reduction; the accuracy, although potentially good, can be obtained only by considerable attention and maintenance. The replacement of the liquid manometer with this electrical transducer eliminates one of the last obstacles to automatic wind tunnel operation and data reduction.

Basically, the transducer consists of a thin neoprene diaphragm which is supported, except for a narrow annulus, by a rigid plate or piston. The piston, in turn, is attached to a strain gage force beam system. The neoprene diaphragm which provides the seal introduces negligible hysteresis, permitting the transducer to operate within an accuracy of 0.1 percent.

Because the transducer is electrically and mechanically simple, rugged, and reliable, it has many potential applications in the measurement of pressure and parameters related to pressure. Possible applications include: remote reading barometers, altimeters, air speed indicators, Mach meters, pneumatic gaging and positioning, and industrial controls.

vibrating diaphragm pressure transducer

(potential)

A vibrating diaphragm pressure transducer was developed to meet the pressure measuring needs of new wind tunnels at NASA's Ames Research Center. The principal attributes of the transducer are its wide measuring range, high sensitivity, fast time response, good temperature characteristics, small size and gage volume, ruggedness, ability to withstand over-pressure without damage, and its compatibility with most electronic readout and recording equipment. The gage is capable of measuring pressure from approximately 10^{-5} to 10^{3} mm. Hg. with an accuracy of about one percent and a time response of less than one second over a large portion of this range.

This transducer may be physically described as a small closed cylinder which is partitioned into two enclosed cylindrical chambers by a thin metallic diaphragm. These chambers are of equal volume and are connected to a common gas inlet tube so that the two sides of the diaphragm are subjected to equal pressure at all times. The diaphragm is driven electrostatically with a capacitance bridge. The amount of power necessary to drive the diaphragm at constant amplitude is measured, and this measurement is directly related to the pressure.

In addition to its use as a pressure gage, this transducer shows promise as a sensing element for several additional applications. It could be used as an altimeter, to altitudes as high as 400,000 feet. It has a very large input impedance and could be used as the sensing element in an electrometer circuit. It could also be used to measure magnetic damping by making suitable changes in techniques and materials of construction.[9]

manometer with electronic follower

With the adaptation of automatic data reduction for research performed in wind tunnels at Ames came the need for a very accurate pressure reference with a digital output.

A mercury-in-glass manometer was equipped with a metal float with a movable differential transformer surrounding the mercury-tube-float combination. By means of a motor driven screw and electronic servo amplifier, the differential transformer was made to assume a vertical position determined by the position of the metal float. By attachment of a counter or analog-to-digital converter to the motor driven mechanism, either a visual or electrical digital output, or both, can be obtained. Accuracies of 0.002" to 0.005" of mercury are obtained. The device is finding commercial application in liquid level and pressure measurement.

Lockheed Electronics Company
Plainfield, New Jersey

piezo-resistivity in silicon carbide

(potential)

In the section of this report on Resistance Strain Gages, it was reported that Lockheed Electronics discovered a palladium-silver alloy. The discovery was the result of work which the firm had been doing under a Department of Defense research contract to find materials suitable for accurate operation as strain gages at very high temperatures.

That same materials search led to the discovery of piezoresistivity in silicon carbide. Briefly, this means that the material changes its electrical resistance when a force is applied to it. Although there has been no non-space application of this as yet, Lockheed believes that the material has potential in certain applications, such as the heart of a microphone or underwater transducer.

4. Temperature Measuring Equipment

Space and missile requirements have stimulated development throughout the temperature measurement field. These requirements have particularly emphasized reliability, convenience of use, multipoint system, response time, and methods and equipment for achieving accurate results under adverse conditions.[10] In a complex vehicle, such as a missile or satellite, there are many components, units, and systems where temperature or temperature environment must be monitored and controlled within safe operational limits. These temperatures vary from the low range of cryogenics and the upper atmosphere to the high range of re-entry and the combustion chamber. The safety of any living occupants and the proper functioning of equipment depend unequivocally upon measurement and control of temperature.

The temperature measuring devices which have found missile/space application have been primarily the two common types which provide electrical output, i.e., thermocouples and resistance temperature sensors (including thermistors). These devices have been in common use for many years, their origin dating back to the nineteenth century. Thermocouples are applied largely in moderately high to extremely high temperatures, and resistance sensors in moderately high to extremely low temperatures. There is, of course, a large overlapping range. In addition, specialized optical and radiation techniques are used for temperatures above the thermocouple range.

In the high temperature field, it cannot be said that there has been a great deal of thermocouple development specifically for space needs. There has been a general and increasing interest in this temperature range, leading to thermocouples for temperatures up to approximately 5000°F.[11] It is probable that the incentive for most of this development has come from the metals industry, with some indirect impetus from missile/space programs. Possibly the most specific missile/space connection in this area is the development of special mountings and configurations for specific missile and rocket related purposes.[12]

In the moderately high to extremely low temperature range, the impetus from missile/space research is more noticeable. The apparent reason for this is that the low temperature field had fewer factors contributing to its development prior to space research than did the high temperature field.

Semiconductor and thin film resistance temperature sensors have been developed and may be expected to have much application to missile/space research because of their rugged and simple construction, which makes them relatively immune to severe shock and vibration environments.[13] The primary contribution of the missile/space program to this field has been the impetus to development provided by a number of applications.

The platinum-wire resistance thermometer, which has been a standard laboratory device for many years, has had much development due to space requirements. It has been miniaturized and made rugged and reliable far beyond its typical characteristics as a laboratory instrument. A great part of the resistance thermometer development which is attributable to missile/space impetus has been in the design of units for application in the very low temperature region. These have been stimulated by the use of liquid oxygen and liquid hydrogen in missile and rocket propulsion systems.[14]

Examples of missile/space transfer to commercial applications of temperature measuring equipment follow.

The Lewis Engineering Company
Naugatuck, Connecticut

resistance temperature detector

To meet the harsh environmental conditions of missile usage, the company redesigned an existing temperature detector. This specialized and improved design was then manufactured for the Atlas missile. Modifications of the improved device have since been produced for use in industrial applications.

The non-space applications of this modified device include: use in modern jet aircraft for sensing the temperatures of engine air inlet; an industrial application for sensing temperatures to operate an electronic temperature controller.

The development was funded by the company.

Microdot Inc.
South Pasadena, California

temperature transducer

A temperature transducer with platinum sensors was developed by the company in 1959. Its original use was in rocket motor testing at the Sacramento plant of Aerojet - General Corporation. Special characteristics include small size, high base resistance, and extreme ruggedness. These are achieved through a sensing element of platinum film deposited on a miniature ceramic disk. The company reports that this product has fast response, excellent operational stability, and extreme linearity over a wide range of temperatures.

An interesting use of this transducer outside the missile/space industry is at the Sharp Memorial Hospital in California. The device is implanted into a tumor of either a human or an animal to assist in the determination of the effect of strong temperature changes on the tumor. Artificial temperatures are induced, by drugs or other means, and the sensor is used to accurately measure the temperature inside the tumor.

Development of the transducer was funded by Microdot.

* * * *

The primary advantages of this device over previously available platinum resistance thermometers is its small size and fast response. Commercial potential appears to lie in laboratory and medical uses.

The Boeing Company
Associated Products Division
Seattle, Washington

thermal measurement devices

(potential)

Thermal measurement devices were developed as the result of research on missile temperature measurement by The Boeing Company.

One device, a thermal parameter indicator, will measure from a distance temperatures that exceed the melting points of known thermocouples. In addition, the device will measure the heating rate from any source (radiation or convective) and determine the heat transfer coefficient. These parameters can be measured for time periods as short as 10 milliseconds. The non-space applications of this device, although limited, are expected where reasonably high temperatures (over 2000°F) exist, as in furnace measurement or plasma arc measurement.

Two other devices were developed, a surface temperature transducer and a self-compensating thermocouple. Errors normally experienced with these devices are eliminated and response time is appreciably decreased. The time response for surface applications is reduced to one to ten milliseconds, less than one second on probes where the response time is usually five to 25 seconds. Non-space applications of these devices are expected where high speed response is necessary. Nuclear power plants, where small temperature changes need to be known quickly, are an example of potential use.

These instruments have been licensed to the RDF Corporation, in Hudson, New Hampshire, where further development is currently in progress prior to their introduction on the market.

Trans-Sonics, Inc.
Lexington, Massachusetts

equiphase triple-point-of-water cell

Missile/space activity has increased the applications of standards to such an extent that it is now feasible to manufacture them for the commercial market. These standards are not used directly for the space effort, but the need for precise measurements among many prime and subcontractors on space programs has expanded the use for basic standards considerably. This has made it economically feasible for a commercial product to be offered rather than depending on individual laboratories to manufacture their own standards.

An example of this is the equiphase triple-point-of-water cell developed at Trans-Sonics. This cell is a device for generating the stable temperature established by the triple point of water--the temperature at which the solid, liquid, and vapor phases of water exist in equilibrium. This cell is an improvement over the more commonly used ice and water bath. It is hermetically sealed against the possibility of contamination and barometric pressure effects, and designed to minimize temperature gradient errors.

In general, the device can be used wherever the most accurate and stable defining temperature standard is required. Its characteristics of simplicity and noncontaminability suggest its use also in less demanding applications. Here, accuracy can be assured with personnel who have not been extensively trained in the correct use of a standard.

The primary commercial use of the triple-point-of-water cell is in standards laboratories. Thus, by the very nature of the market, the commercial sales volume has been small.

The development of this product was funded by Trans-Sonics.

Genisco, Inc.
Compton, California

<u>thermo reference junction</u> A temperature measuring device, which was developed by Genisco specifically for missile/space applications, provides a miniaturized multichannel thermocouple reference junction, eliminating the fragile and very limited thermos bottle ice bath. It is used on missiles for measuring temperatures such as the various electronic packages, the missile skin, on and in close proximity to the throat of the missile engine. The device provides a secondary junction reference which is constant, making it possible to measure with great accuracy the temperature of the sensing thermocouple. Its ruggedized package and small physical size make it desirable for missile temperature measurement applications. The thermos bottle ice bath is an extremely good reference for ground applications; however, it has several limiting factors. For example, it must be constantly attended in order to achieve the accuracies which are always available from the hot reference junction.

The company reports that the thermo reference junction also has many other applications in the missile/space industry, as well as in commercial industries. To date, about 100 of these units have been sold commercially. They have been on the market for approximately one year. Specific non-space applications include the petrochemical industry (cracking stations), the food processing industry, remote weather stations (where it is desirable to keep a record of ambient temperature), heat treating plants (where furnace temperatures must be held to close tolerances), and the bio-medical field (where temperature acquisition of various types of rodents are being studied). At the present time, commercial sales account for about 10 percent of the total sales volume. The development of this device was funded by the company.

5. Instrumentation Amplifiers

Instrumentation is concerned with the problem of measuring quantities such as temperature, pressure, humidity, velocity, mechanical strain, voltage, current, resistance, electromagnetic radiation, and nuclear radiation. Measurements usually result in a considerable amount of data--so much that one or even many individuals reading thermometers, dials, or meters cannot possibly assimilate, process, and make interpretations in a reasonable length of time. Often, as in space research, it is unsafe or impractical to have operators in the vicinity of the measurements, thereby requiring remote measurements and telemetry. In addition, many physical phenomena happen too fast to be observed by the relatively slow human. For these reasons data must be collected and processed by machine; this is most conveniently done electronically.

Transducers are the devices which change the measured quantity to proportional electrical signals. But transducer output voltages are low (0. 1 to 10 millivolts) and quite susceptible to degradation by electrical circuit noise. Therefore, transducer outputs must be amplified, usually to a level of one to ten volts, before data processing can occur. Also, a transducer output may have a high impedance level so that direct connection to a data handling system would load and reduce its output. It is then necessary to provide isolation using an amplifier which has a high input impedance and a low output impedance. Since most transducers do not respond to changes which occur faster than 10, 000 cycles per second, the amplifier bandwidth requirement is usually in the DC to 10, 000 cycle per second range. This kind of amplifier is called a DC, direct current, direct voltage signal conditioning, isolation, transducer, or instrumentation amplifier or preamplifier.[15]

The problems concerning instrumentation amplifiers were apparent immediately after the invention of the vacuum tube, in the early 1900's. Commercial need for the amplifiers has grown steadily since. This need has been, of course, linked to the need to measure various quantities and record data electrically. Instrumentation amplifiers are used in almost all disciplines, including medicine, biology, psychology, chemistry, physics, and all branches of engineering. With such widespread usage, development of instrumentation amplifiers occurred prior to World War II and would occur in the future without support from the missile/space programs.

However, recently the missile/space support has been responsible for significant advances in the state-of-the-art. Serious problems in the space program are the development of reliable telemetering systems to relay data from space vehicles to command stations and the development of remote automatic controls activated by transducers. Inherent in these problems is the development of instrumentation amplifiers, which has had considerable industry and government support. Much of the space support has been directed at reducing size, weight and power requirements and making previously developed laboratory type instrumentation amplifiers more rugged by application of recent advances in solid state electronic technology.

The missile/space effort has motivated the development of some special purpose instrumentation amplifiers. One particular problem is to transmit information from many transducers (hundreds or thousands) on a single (or few) radio transmission channel(s) essentially simultaneously, for it is entirely impractical to use a separate radio transmission channel for each transducer. This problem is solved by using an electronic or mechanical commutator which periodically scans transducer outputs rapidly so that transmission of all channels can be considered simultaneous. Scanning can be accomplished in two ways: high level and low level. High level scanning requires one instrumentation amplifier for each of the many transducers to increase signal so that scanning circuit noise problems are avoided. The need for hundreds and thousands of instrumentation amplifiers has caused engineers to consider scanning low level transducer outputs directly in spite of additional noise problems, thereby requiring only one or two instrumentation amplifiers. These special purpose instrumentation amplifiers must have wider bandwidths (DC to approximately several hundred kilocycles per second) to be able to respond to the rapid functioning of the commutator.[15] (See the Epsco description below.)

It seems that the most significant contribution of the missile/space programs in this area is equipment availability. Although this statement and the company examples which follow may at first seem vague, the contribution is very real. The instrumentation amplifier--like the voltmeter or oscilliscope--is an ubiquitous piece of industrial laboratory and testing equipment. As mentioned above, it finds use in almost all scientific disciplines and all branches of engineering. Therefore, although some of this equipment may never find commercial use, it is reasonable to expect that much will, simply because this equipment is such a necessary adjunct to the electronic measurement of physical quantities. Electronic measurement is already widespread and will become more so as better and more variegated equipment is made available.

Examples of missile/space contributions to instrumentation amplifier development follow.

Acromag, Inc.
Detroit, Michigan

<u>isolation amplifier</u>

(potential)

Acromag, a firm specializing in the development of precision magnetic amplifiers, has developed an isolation amplifier which operates at a 10 millivolt signal level with three hundred million to one DC common mode rejection. This amplifier was developed under a fixed fee contract with the Lewis Research Center, NASA, to amplify the output of a thermocouple attached to an ion propulsion engine high voltage electrode. Complete redesign and repackaging of a second harmonic magnetic amplifier for operation in high voltage environments (30 kilovolts DC common mode) went into the development of the amplifier. The company feels that since severe common mode problems are common to users of instrumentation amplifiers, the product has potential in both missile/ space and commercial industries.

<u>transistor-magnetic amplifier</u>

(potential)

A new hybrid push-pull transistor-magnetic amplifier, which operates like a magnetic amplifier but more effectively, has been developed by Acromag. Developed to replace larger and heavier amplifiers used on the Atlas, Titan, and Bomarc missiles for remote control, this amplifier is about one-seventh the size and weight of conventional magnetic amplifiers. Acromag has no present commercial market for this item but anticipates that it will be used in future aircraft autopilots. Non-airborne uses are anticipated to be small.

Development of this product was funded by Acromag.

Burr-Brown Research Corp.
Tuscon, Arizona

<u>DC amplifiers</u>

Burr-Brown makes a line of solid state DC operational amplifiers which are generally sold to the electronics industry, research laboratories, and universities for signal conditioning, precise gain, and analog instrumentation. The company feels that the space and missile programs have forced overall improvement in this line of equipment.

Epsco Inc.
Cambridge, Massachusetts

<u>low-level, wide-band amplifier</u>

(potential)

Epsco has developed two special purpose instrumentation amplifiers for missile telemetry systems. Both are improvements of previously existing types.

The first is a chopper stabilized, low-level, wide-band, DC amplifier weighing four ounces and occupying thirteen cubic inches. The amplifier has a common mode rejection of one million to one and a highly stabilized gain. Epsco believes this amplifier to be the smallest available precision wide-band amplifier on the market.

<u>potentiometric amplifier</u>

(potential)

The second device is a potentiometric or isolation amplifier which is chopper stabilized having a gain of unity and wide-band from DC to several hundred kilocycles. The input impedance is 20 megohms.

Neither amplifier has been incorporated into commercial data processing equipment to date, but Epsco anticipates that they will be in the future because of simplicity of use, maintenance, and eventual overall cost reduction.

commutator

(potential)

Another Epsco product falling into the general instrumentation amplifier field is a solid state, high-speed, precision, time-division commutator which connects a number of low level inputs to a common output differential bus. This was developed for missile telemetry under the Titan II program and is a modification of another component. Epsco's improved commutator is now available for use in commercial data processing, where it hopefully will make a system simpler, cheaper, and easier to use. It is now in the process of being introduced to the commercial market.

Santa Barbara Research Center
Goleta, California

transistorized preamplifiers

(potential)

The Santa Barbara Research Center designs, develops, and produces infrared detectors and allied components. In connection with several missile/space programs, it has developed a transistorized preamplifier, which provides large voltage gains without introducing excessive noise when used with a wide variety of photodetectors. This preamplifier, essentially an improvement of earlier designs due to the availability of better components, was developed largely under NASA systems funding, and partially with company general research funds. Preamplifiers similar to this will be used on the Surveyor Star Tracker, Nimbus radiometer, and Nimbus horizon scanner. This amplifier is useful for any military application which requires high performance of bolometers (heat sensing devices) or photocells.

* * * *

Although the company reports no non-space applications of this preamplifier, it could be useful with or without the photodetector for research instrumentation and industrial control.

6. Miscellaneous

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California

blackbody reference

(potential)

In the selection of materials for use in space, it became necessary to measure the change in emissivity of various surfaces when exposed to actual space flight conditions over a long period of time. These measurements were to be made by comparing the equilibrium temperatures of isolated test surfaces with the temperature of a blackbody reference surface having stable characteristics under space environment.

Since no material was available which possessed these characteristics, a very satisfactory blackbody reference surface was devised by stacking razor blades together to form valleys. This causes the incident radiation to be reflected from wall to wall of each valley a number of times before being reflected outward.

The reflected radiation escaping from the system is small since a large percentage of each reflection within the system will be absorbed by the surfaces. Because of the large number of the reflections, any change in the emissivity of the individual surfaces has only a very small effect on the overall emissivity of the reference surface. Hence this surface has a nearly constant emissivity even though the condition of the individual surfaces might change in the space environment. The rows of razor blades are arranged in a hexagonal pattern to minimize any directional effect which might result from the stacking of the blades.

The edges from the razor blades, in strips 1/16 inch wide, are given a blackened finish and stacked side by side across a copper disc to form an assembly 3/4 inch in diameter. The blackbody equilibrium temperature is determined by thermistors mounted in the middle of the copper base.

Blackbodies are used by many laboratories as reference devices, especially in the field of spectroscopy. Types now in use are bulky and consequently difficult to maintain at any reference temperature. The razor blade device developed by Ames is small and compact. It makes possible the construction of small hand-held instruments.

* * * *

As the above information obtained from Ames points out, there are numerous requirements for blackbodies other than space applications. In most of these applications, the blackbody is used as a reference source in absolute measurements and therefore the requirement is for a source (preferably with an emissivity approaching unity) whose emissivity remains constant over a wide range of temperatures and for long periods of time.

It has been known for many years that it is possible to approximate a blackbody very closely by making a small hole in the side of a hollow enclosure. Theoretically, such a hole would have to be infinitely small in order for it to behave as a blackbody. In practice, it is possible to make blackbodies with emissivities in excess of .99 by proper choice of the size hole and dimensions of the enclosure. Theoretical calculations have been made of emissivity as a function of size of aperture and dimension of enclosure in a number of cases where the enclosures had standard geometrical shapes (sphere, cylinder, etc.). The results obtained are summarized in an article by Rutgers.[16] In all of these cases, it is necessary that the hole be a small fraction of the dimension of the enclosure. Thus a blackbody constructed in this fashion is bulky compared to the area available for use as a source.

Numerous methods have been developed to increase the emissivity of flat surfaces. It is possible to obtain surfaces with emissivities in the infrared in excess of .9 by coating the surface with various materials. The disadvantage here is that the emissivity of the surface may change with time. Also, it is not possible by this method to obtain emissivities much greater than .93.

The approach used by the Ames Research Center appears to be a compromise between the two methods, as it avoids the large size necessary on one hand and the problem of the change of surface characteristics on the other. According to Ames, its blackbody has an emissivity of about .93; it varies approximately two percent over a temperature range of 100°F. These characteristics are not adequate for laboratory blackbodies; however, Ames points out that it may be possible to obtain higher, less temperature dependent emissivities by proper spacing of the razor blade edges.

There are other methods of obtaining high emissivity surfaces similar to those suggested here, but which are more amenable to theoretical treatment. One of these is a method employed by the University of Wisconsin's Meteorology Department for use in connection with its satellite radiometer program. The program required a large hemispherical blackbody. It was constructed by placing many .38 caliber revolver cartridges as close together as possible in the form of a large hemisphere.

Using this approach, one is dealing with a surface composed of a large number of small blackbodies whose emissivities can be calculated theoretically. One difficulty with both approaches is that a certain portion of the surfaces will be composed of the edge of the razor blades or the walls of the revolver cartridge and hence the emissivity cannot be made to approach unity as closely as might be desired. However, because both approaches yield relatively high emissivities that theoretically should not vary with temperature, they may be refined and used to construct small, inexpensive reference surfaces.

Electro-Optical Instruments, Inc.
Monrovia, California

Kerr Cell camera

Electro-Optical Instruments manufactures the Kerr Cell camera which will take pictures with an exposure time as brief as 5 billionths of a second (5 nanoseconds). The shutter consists of two electrodes immersed in a fluid, nitrobenzene. When oriented between two polarizers, which are crossed for minimum light transmission, the cell constitutes an electro-optical shutter. When a voltage pulse is applied to the electrodes, the plane of light polarization is rotated in the fluid, and light passes through both polarizers. The factor limiting the speed of the camera is the length of the electronic pulse.

The relationship of the camera's development to the missile/space effort is not clear-cut (the Kerr effect itself has been known for approximately a century). However, it can be said that the missile/space effort has accelerated the development of a sophisticated Kerr Cell camera, mainly because it has provided a significant demand. The camera is used by researchers in the missile/space industry to study plasma gas discharge, shock waves, and hypervelocity impact. There are also research applications outside the missile/space industry; for example, the study of explosive detonation.

The recent extension of the older single frame instrument to a six frame device with recording capability in the 100,000,000-frame-per-second range was primarily stimulated by missile/space industry requirements. Most applications of this newer system are coincident with increased research effort in the missile/space field.

Avco Corporation
Research and Advanced Development Division
Industrial Products Subdivision
Lowell, Massachusetts

rotating drum & rotating mirror cameras

These cameras are research devices designed to provide scientists with time resolved photographic data of hypersonic phenomena. Their development began in conjunction with work Avco was performing on the Air Force ballistic missile program. Actually, these cameras are not entirely new developments. Similar units, usually custom built by the user, have been in use for many years. However, the development of a commercial line by Avco was made possible largely by missile/space program requirements. Therefore, the space program has contributed to these products by making them more commercially available.

The rotating drum camera may be employed by itself to make position-versus-time records of hypervelocity phenomena. It may be used with a densitometer to produce accurate densitometric data of hypervelocity phenomena. It may also be used, in conjunction with a schlieren system with special light source, to produce microsecond-order photographic frames for graphical analysis of hypersonic phenomena. A precision manufactured drum with film attached constitutes its only moving part and provides the high degree of accuracy and reliability required.

The rotating mirror camera is an easy to use, rugged research instrument. Continuous optical records of hypervelocity phenomena are obtained by means of a highly accurate hexagonal mirror, rotating at 3,000 revolutions per second. This camera differs from the drum camera in that light is reflected from the mirror to the film on the inside of the case, and it is capable of higher speeds.

Applications of these cameras, other than in ballistic missile studies, include: radiation studies, explosive compound development, combustion studies, ignition studies, propulsion studies, chemical recombination, plasma tunnel studies, magnetohydrodynamics, spark-gap discharge studies, exploding wire studies, and studies of high speed electromechanical units and relays.

The Boeing Company
Associated Products Division
Seattle, Washington

Two instrumentation devices, qualifying as by-products, have been developed by the Boeing Company as a result of its participation in missile, space and aircraft programs.

Beta Backscatter thickness gage

One is a Beta Backscatter thickness gage. This instrument obtains accurate measurement of thin sheets or coatings of metal by exposing the coating to a radiation source and counting the scattered radiation. The gage is highly accurate over its range, varying from thicknesses of .0000005 inch to .010 inch. The majority of applications require determination times of only three minutes or less.

The film to be measured is placed over a one inch diameter hole. The radioactive material is supported 1/4 inch below the film and is exchangeable, thus allowing the use of any desired beta energy. Below this is a thin window Geiger counter with an amplified output signal. For convenience and safety the equipment is enclosed in a 12" X 12" X 8" plexiglas box.

The gage provides a rapid non-destructive means of accurately determining very thin film thicknesses. Other methods are limited in their usefulness and accuracy, since they involve cutting or otherwise destroying the film.

This instrument has been licensed to the Twin City Testing Corporation and a number of units have been sold. The electronic industry is the biggest user of this instrument, both for missile/space and commercial applications. Typical commercial applications include the measurement of printed circuit boards and plating thickness on solid state retainer cups.

optical measurement and depth gage

The second device is an optical measurement and depth gage. Fully developed, this instrument simplifies and improves detail inspection, achieving accuracy to tolerances of .00015 inch without touching the workpiece. The gage obtains measurements that previously were extremely difficult or impossible, such as accurate measurement of parts at elevated temperatures and measurement of latex, other soft materials, wet paint thicknesses, photo etching depth, curved surfaces, and certain kinds of parts in motion. The instrument measures mirror-shiny and dull-black surfaces with equal ease.

Measurements are based on the observation of the coincidence of two straight lines, which can be more accurately judged by the human eye than other forms of coincidence such as circles or filament images. The accuracy of the instrument is limited only by the accuracy of the indicator. A number of indicators can be used, such as a dial indicator or a vernier height gage. The effective focal length ranges from 1-1/2 inches to 12 feet.

Minneapolis-Honeywell Regulator Company
Heiland Division
Denver, Colorado

1108 Visicorder

The 1108 Visicorder is an improvement or extension of the direct writing oscillograph. Historically, recording oscillographs are associated with petroleum exploration work. As the need for static or dynamic testing of aircraft components increased, the oscillograph was improved and changes were made in its utility and configuration.

This equipment is utilized in the missile/space program in many ways: to test rocket engines; to provide information during launchings; to graphically present post launching information from telemetry channels; and as a laboratory tool to acquire information about components under environmental tests.

As a result of its use in the missile/space program, the device has been improved in several ways. Reliability has been greatly enhanced. Several automatic features have been added to give ease and flexibility of operation, and the capability of immediate review of data has been added.

The improved Visicorder is used throughout industry as test equipment for acquiring high frequency (5 - 5,000 cps) analog data. Commercial applications include the following industries: automotive, light and heavy equipment, electric motors, electronic components, and household appliances.

<u>spectrum analyzers</u> Minneapolis-Honeywell's line of spectrum analyzers was developed originally to fulfill the need for vibration analysis in late model aircraft. However, the missile/space industry has provided the bulk of the requirements for this type of device. In addition, missile/space uses have required a more sophisticated product than was needed for aircraft vibration studies.

Vibration is one of the more difficult problems in the successful launching of a missile or space vehicle. Rocket engines produce noise and vibration across the entire spectrum. Every component, as well as the completed assembly, must resist deleterious effects from given frequencies. As a result of these requirements, certain improvements have been incorporated into the equipment.

The improved equipment has been used commercially in many industries which have vibration test facilities, such as automotive and household appliances.

General Precision, Inc.
Librascope Division
Glendale, California

<u>multi-layer dielectric interference filter</u> The Research Center, Information Systems Group of General Precision, Inc. has developed a technique for producing multi-layer dielectric interference filters. The filters were to be used in missile tracking as they would greatly reduce background, allowing only the rocket flame to be seen through the filter.

These filters have potential application in the field of chemical process control where a property called "selective absorption" can be used. White light passing through a transparent medium is absorbed in an amount which varies progressively,in general, with the radiation frequency. However, certain frequency ranges are absorbed in an amount out of all proportion to adjacent frequency; in other words, by selective absorption.

The particular pattern of selective absorption varies with the kind and concentration of the material being studied. Therefore, a filter designed to pass a certain frequency can be used to monitor the amount of light selectively absorbed in that frequency range, and hence the concentration of the chemical being monitored.

An interesting application of General Precision's filters has been in the field of egg candling. Federal laws prevent the sale of eggs having blood spots in them which exceed a certain minimum size. Blood has a selective absorption band at 5,500 angstroms. A machine, designed by the Research Center, is being sold by Food Systems, Inc. of San Francisco. This device passes light through an egg and by comparing the light absorbed at 5,000 angstroms, 5,500 angstroms, and 6,000 angstroms, using interference filters designed to pass light at each of these frequencies, the machine can spot and sort eggs which contain blood spots in excess of legal size.

The development of the technique to produce these filters was funded by the Research Center.

* * * *

The basic theory underlying the design of multi-layer interference filters (filters that will transmit a very narrow band of radiation centered around any given wavelength) has been known for many years.[17] Not until the early 1950's, however, did the techniques of depositing uniform layers of the proper thickness of dielectric material develop to the point that filter construction was practical. Such filters have many applications in weapons systems being developed by the Department of Defense as well as several applications in the space program.

Many applications exist where it is necessary to monitor the radiation emitted by a source in a very narrow, selected wavelength interval. Spectrometers of various types can usually be used for this task. However, when the intensity of the source is low or the environment is harsh, the use of an interference filter may be desirable. Thus the interference filter has many space and defense, as well as commercial, applications.

B. ELECTRONIC COMPONENTS AND MISCELLANEOUS SYSTEMS

1. Semiconductors

Semiconductors are a class of materials whose electrical conductivity is intermediate between the conductivities of metals and insulators. A wide variety of solids, liquids, elements, and compounds exhibit this behavior. The most commonly used semiconductors today are germanium and silicon, though compounds such as gallium arsenide, lead sulfide, or zinc oxide find many specific uses.

The crystalline structure of semiconductors is usually such that each atom shares one of its valence electrons with each of four neighboring atoms (covalent bonding). Since all the outer electrons are required to form such a bond, none is free to move about. Thus a semiconductor in its purest crystalline form is a poor conductor.

Addition of heat or radiant energy will cause some electrons to break loose and travel through the crystal. An atom, losing its electron, will assume a positive charge. This atom can transfer its positive charge to a neighboring atom by capturing one of its neighbor's electrons. Thus a semiconductor can conduct either by the movement of electrons or the transfer of positive charges, called holes.

"Doping" a semiconductor with small amounts of an impurity also causes an increase in conductivity. Semiconductors are doped with either five valence electron elements, called donors, or three valence electron elements, called acceptors. A donor atom enters the crystal structure of the semiconductor, and since only four of its five outer shell electrons are used to form the covalent bonds, the fifth electron is free to move about. Because negative charges are donated, a semiconductor containing donor atoms is called an N-type semiconductor. Acceptor atoms can also become integrated into the crystal structure. Having only three electrons available for bonding, an acceptor robs its neighbor of the fourth, producing a concentration of positive charges or holes. A semiconductor containing acceptor atoms is called a P-type semiconductor.

A P-region and an N-region formed in the same crystal produces a rectifier or diode--a device which is far more conductive in one direction than the other. The boundary between the two regions is called the P-N junction.

While a P-N junction or diode finds many applications in electronic circuitry, it is not able to amplify a signal (with the exception of the rarely used tunnel or amplifying diode). The transistor or three-terminal semiconductor will amplify a signal and therefore finds innumerable applications in electronic circuits. A transistor may be considered as two P-N junctions back to back, forming either an N-P-N or P-N-P junction. By applying proper voltages to the three leads--emitter, base, and collector--the transistor may be used as a replacement for the vacuum tube. It is then capable of performing almost any function of a vacuum tube.[1]

The first crude semiconductors that found application in electronics were the "crystal and cat-whisker" detectors used in radio receivers in the early twentieth century. The semiconductor material used in these devices consisted of crystals found in the natural state. As these were unrefined semiconductors, their characteristics varied and they were unreliable. These crystal detectors were replaced by the vacuum tube and remained an experimentor's novelty until the advent of radar in the late 1930's. The electron tube that had functioned so well as a detector at broadcast frequencies became useless at very high radar frequencies, and interest in semiconductor detectors was revived.

While the diode detectors used in the early radar sets were a vast improvement over the old crystal and cat-whisker detectors of radio, they were inferior to present devices and more costly. During the late 1930's and into the 1940's, methods of refining germanium or silicon were costly and erratic. The difficulty of producing units with identical characteristics necessitated much testing and selecting, resulting in high priced and occasionally unreliable units.

As techniques for improved production of semiconductor materials developed, interest in these devices increased. The first breakthrough in semiconductor device production was the invention of the point contact transistor in 1947. Bardeen and Brattain of Bell Telephone Laboratories produced the first practical unit in December, 1947.

From the beginning, the transistor became a logical candidate for replacement of the vacuum tube. It was smaller, more rugged, operated from much lower supply voltages, and required no heater or filament voltages. The latter advantage eliminated high equipment operating temperatures, eliminated one power source, and increased operating efficiency.

While the first point contact transistor was limited to amplification at lower frequencies, subsequent developments by Bell Labs and other companies overcame this problem. Limitations of these early transistors were due in part to poor quality semiconductor material. At that time it was difficult to control the degree of impurity in the silicon or germanium used in the production of the device. The degree of impurity is an important factor in determining the subsequent device's operating parameters.

Germanium was the first semiconductor to be refined with accurately controlled amounts of impurity. Thus many of the early transistors utilized germanium. Zone refining, one of the best methods for purification of germanium, was developed around 1950.

Silicon semiconductors are often more desirable than germanium. The principal advantage of silicon is that it can operate at higher temperatures and thus offer higher reliability. This is especially true in the field of missile/space electronics, where high ambient temperatures may prevail. Unfortunately, attempts to refine silicon by the same methods used on germanium failed. (Silicon's ability to operate at higher temperatures is reflected in the higher temperatures required for purification.) Induction heating methods that worked for germanium purification were difficult to apply to silicon. But initial problems were overcome and silicon became a practical semiconductor material.

Concurrently, development was progressing in the production of P-N junctions in the crystal forming process. This was achieved by adding various amounts of impurities to the crystal while it was being formed. Thus point contacts or cat-whiskers were eliminated, and a solid junction then formed the P-N device. This resulted in greater mechanical stability and reliability.

Methods for forming P-N junctions other than the grown junction technique include the alloy technique developed in 1952 and the diffusion technique developed in 1956. In the alloy technique, dots of impurity are fused to the semiconductor to form a junction. In the diffusion technique, the impurity is transferred in the gaseous state to thin semiconductor wafers. The reaction between the two results in a closely controllable process that can be duplicated.

The diffusion process subsequently led to the "drift" transistor and the micro-alloy diffused transistor (MADT). These units have higher frequency capabilities than their predecessors. Other developments that have recently raised frequency limits and operating powers are the mesa and epitaxial mesa techniques. The mesa transistor is a silicon diffused base device, while the epitaxial mesa is a modification of this technique that further increases frequency range.

While much work has been done with silicon and germanium, experience gained with these elements has proved useful in the development of other semiconductor devices. Indium antimonide and gallium arsenide are intermetallic semiconductors that are useful in constructing a wider range of devices than can be made with either germanium or silicon.

Other semiconductor devices that have been developed as an outgrowth of transistor and diode research include: the Zener diode, variable reactance diode, microwave signal diode, silicon rectifier, silicon controlled switch and four layer diode, silicon controlled rectifier, tunnel or Esaki diode, unijunction transistor, field effect transistor, photoconductor, photovoltaic or solar cells, gallium arsenide diodes or semiconductor lasers, thermistors, thermoelectric coolers, thermoelectric power generators, and Hall effect or magnetoresistive devices.

The major advantages of semiconductors over vacuum tubes or electromechanical relays are ruggedness, and reduction in size, weight, power requirements, and maintenance. Therefore, semiconductors are in demand for industrial applications and are ideal for military or space applications. Although semiconductor development would have evolved on a commercial basis, the space, missile, and military programs have accelerated development and notable improvements have resulted. Major problems concerning semiconductor application in the missile/space program fall into two categories: the need for reliability and the need for operation in severe environments. Reliability is important because maintenance cannot be provided in most missile/space applications. Some of the most reliable components have been developed for the missile/space program. Reliability is important in commercial use as well, although the need is not as critical.

Missile/space application requires operation over wide temperature ranges and operation in fields of high nuclear radiation. Undoubtedly, the development of semiconductor devices from materials which can operate at these higher temperatures has been accelerated by these programs. Both silicon and gallium arsenide have temperature characteristics superior to germanium, and the requirements of the military and missile/space programs have stimulated much development in these two materials. (Most of the transistors used in entertainment electronics are germanium; however, silicon is preferred for industrial or military electronics.) Although most transistors used in industrial applications do not encounter severe environmental conditions, a transistor built to operate over a wide environmental range has, in most cases, more constant characteristics in normal environments. A great achievement in the past decade has been the development of means to volume produce such precision devices without sacrificing quality.[2]

Most semiconductors degrade drastically when subject to radiation. Thus semiconductors exposed to radiation in the Van Allen belts could degrade sufficiently to cause equipment failure. The field effect transistor shows promise as a device that is not greatly affected by this radiation. The field effect transistor maintains its gain under radiation but reduces gain of equivalent standard transistors to 40 percent. When the standard transistor has completely degraded from radiation, the field effect unit still maintains 70 percent of its gain.

The ISA Journal poses this question: How are instruments and communications systems going to survive months' or years' long journeys into space? It goes on to comment that RCA has some solutions based on a four-year research and development program. Highlights include: 1) long life, high reliability. In an isolated facility under controlled temperature, humidity, and dust free conditions, RCA is trying to develop transistors with a theoretical life expectancy of 100 million hours. 2) High power, high frequency. New transistors developed with superior power and frequency characteristics will permit complete transistorization of instruments and telemeters. Some newly developed transistors will handle up to 8 watts at 200 megacycles. 3) Size, speed. A new transistor developed for a computer is one-fifth the size of its counterparts and operates at twice the speed. An N-P-N mesa, developed under this program, handles one billion signals per second and should permit the design of new logic circuits for computers. 4) Efficiency. The use of gallium arsenide in solar cells permits a new high efficiency of 13 percent.[3]

Much development work in the semiconductor field is indirectly attributable to the missile/space program. A typical situation would involve an equipment manufacturer who has a contract for the space program to produce a system which would have to meet extreme environmental and reliability specifications. The equipment manufacturer in turn would have to purchase semiconductor components for incorporation in his system. His demands upon a semiconductor manufacturer would necessitate that the manufacturer perform sufficient research and testing to insure the quality of his devices. Thus the semiconductor manufacturer would be required to maintain high caliber technical personnel and rigid production procedures to meet the specifications. The knowledge acquired to meet specifications as a supplier to a missile/space contractor will certainly not be discarded when the semiconductor components manufacturer is producing commercial components. Much of the art that he achieved would be directly transferrable to a commercial operation.

Examples follow of transfers of technology between missile/space and commercial work in this field as reported by individual firms.

Texas Instruments Incorporated
Dallas, Texas

silicon transistors

Although Texas Instruments can identify no specific missile/space contract where there has been direct by-product spill-over, the company states that the entire field of silicon transistors would be in a far less sophisticated state of development without the advanced application to the missile/space market. In the earlier stages of their development, silicon transistors were used almost entirely in missile/space applications, due to the fact that they can operate at higher temperatures than germanium devices.

In a statement in the Commercial and Financial Chronicle, January 1963, TI's President, P. E. Haggerty, points out that government markets accounted for a major portion of electronics industry sales in 1962. Total electronic industry sales amounted to $13 billion in 1962, of which an estimated $7.5 billion derived from military, space, and other government markets. With this broad support, it would be difficult to find electronic developments that were not affected by government stimulus and related to the missile/space effort. TI's own technical effort represents expenditures of over $40 million annually. About 60 percent of this was company funded in 1962 with the remainder supported by others, chiefly the Department of Defense.

It is of interest, too, that technologies developed first for commercial applications are now being applied by Texas Instruments in the missile/space effort. Techniques and instrumentation developed originally for geophysical surveys are now being used to probe space.

To sum up, about one-half of TI's R & D has been sponsored by and directed toward the nation's defense, missile, and space needs; much of this effort is applicable to commercial electronics, present and future. To look upon specific developments as "by-products" may not be meaningful in the case of Texas Instruments; it is more meaningful to look upon the total effort, noting that TI's commercial effort has missile/space application and vice versa. In other words, both contribute to each other.

General Electric Company
Semiconductor Products Department
Syracuse, New York

reliability techniques

Several types of high reliability transistors were developed by the Semiconductor Products Department of the General Electric Company to meet specifications required by the Minuteman missile program. Development effort centered on device design and workmanship. One-half of the funds were provided by the General Electric Company; the other half by North American Aviation corporation which, in turn, obtained the funds from the Ballistic Systems Division of the Air Force. (However, on two of the transistor types, all of the funding came from General Electric.) General Electric funds were earmarked for overall engineering and manufacturing; government funds for the measurement part of the overall effort.

The class of transistors (grown-diffused on a fixed bed mounting) on which development effort was placed was in existence prior to the missile/space programs. These programs enabled the reliability of this class of transistor to be improved in shorter time and in greater degree than would otherwise have been the case. The high reliability types of transistors were designed to perform amplification and switching functions in Minuteman. Some of the knowledge gained from the Minuteman Missile Reliability Program has been used on commercial and industrial transistors in existence prior to the Minuteman program to improve their reliability. These commercial and industrial transistors are used for control and computer applications. A very small percentage, if any, of the types specifically developed for the Minuteman program are sold for commercial and industrial applications.

North American Aviation, Inc.
Autonetics Division
Downey, California

<u>reliability</u>

Autonetics, working on the Minuteman program, has helped pioneer the development of semiconductor devices which are two orders of magnitude more reliable than their pre-Minuteman counterparts. Commercial versions, incorporating much of the knowledge gained, are being sold.

Merck & Company, Inc.
Merck Sharp & Dohme Research Laboratories
Rahway, New Jersey

<u>diode and transistor substrates from gallium arsenide</u>

Gallium arsenide is an old semiconductor material. As a substrate for consumer rectifiers and transistors, it has not shown sufficient advantages over silicon and germanium to lead to any large scale applications. The response of this material to space environment, the solar radiation spectrum, and to high temperatures, however, has led to applications of gallium arsenide in solar cells, special transistors, and diodes operating at the extreme rocket-missile temperatures. Both of these developments have in turn advanced the gallium arsenide materials and application technology to a stage where the use of this semiconductor is now being investigated in a number of consumer areas, such as tunnel and varactor diodes. The present non-space applications of the material are in specialty devices in relatively small volume. Its ultimate potential is not really known. These developments have been funded by Merck & Company, Inc.

Radio Corporation of America
Semiconductor and Materials Division
Somerville, New Jersey

<u>gallium arsenide semiconductors</u>

(potential)

RCA's Semiconductor Division has done a great amount of research and development on gallium arsenide semiconductors. Original impetus for the work came from the Air Force B-70 program, but later impetus came from missile oriented Air Force sponsored follow-on studies.

Gallium arsenide semiconductor work was originally pursued because a gallium arsenide semiconductor device can operate at higher temperatures than one of silicon or germanium. Operating characteristics, however, are also better in many cases at lower temperatures. As work progressed, it was found that a gallium arsenide switching diode has a much faster switching speed than anything known to date. Gallium arsenide varactors were discovered to have superior frequency response characteristics. Gallium arsenide solar cells demonstrated improved radiation and temperature resistance over silicon cells.

Although gallium arsenide devices have been limited to missile/space applications thus far, their fast switching speed indicates computer uses. Their excellent frequency response has application to microwave communication.

reliability
miniaturization

Transistor development in general has been accelerated by the missile/space effort. One certain manifestation of this is the very advanced state of development of silicon transistors in the U. S. This includes almost all applications, commercial and military.

Space and military inspired miniaturization and reliability have commercial carry-over. At first, miniaturization was pushed for its own sake, but soon RCA realized that with miniaturization comes reliability and ease of production. As electronic circuits are miniaturized, they are made as a unit rather than as a combination of separate wires and components. Less hand operations are required; fewer connections can go wrong. Production costs have already been reduced due to ease of assembly.

Motorola, Inc.
Motorola Semiconductor Products Division
Phoenix, Arizona

semiconductor
reliability
and integrated
circuitry

The product line of Motorola Semiconductor Products includes over 5,000 different items. While it is impossible to evaluate the effect of the missile/space program on each item, a qualitative evaluation of the effect on the product line as a whole can be made.

Many of Motorola's transistors and diodes go into the missile/space program. In general, the missile/space program makes itself felt by inducing improvements in existing devices or, in some cases, making a device commercially saleable by supporting the early production phase.

Surface passivation and other techniques have resulted in highly reliable transistors. The missile/space program's need for reliability is felt whether or not Motorola is working on a specific Air Force, Navy, Army, or NASA program.

Unquestionably the major reason for Air Force research and development in integrated circuitry is missile/space application. Motorola is a major factor in the Air Force program. The company states that this plus other effort going into the development of integrated circuitry will have an impact on the industrial and entertainment electronics market (see section on "Microsystems Electronics" immediately following).

Initial development of all Motorola's missile/space products was funded by the company. Several devices have been modified and refined for the Army, Navy, and Air Force. Many of these refinements are being, and will be, used in Motorola's commercial line.

Clevite Corp.
Clevite Transistor Division
Palo Alto, California

Shockley
diode

The Shockley diode (or four layer diode) is a two-terminal silicon semiconductor switch. It has two stable states: the off or on high impedence state and the on or low impedance state.

The Shockley diode has been used in both the Sidewinder and Polaris missile programs, and the market for this device is split about 50/50 between military and commercial use. The company states that missile/space effort has contributed significant impetus to the development and marketing of this switching device. Its most significant applications in the missile/space efforts have been in timing devices, pulse generation, and powering actuators.

Commercially, the Shockley diodes are used in measuring and counting instruments, alarm systems, pulse modulators, time delay or timing circuitry, and telephone switching.

2. Microsystems Electronics

Microsystems electronics (microelectronics) is the science of miniaturizing electronic circuitry. Although there is some confusion in terminology due to the newness of the field, microelectronic circuits may be divided into three categories: 1) semiconductor integrated circuits, 2) thin film circuits, and 3) modular circuits.

Semiconductor integrated circuits are formed on an active substrate such as silicon or germanium. Both active circuit elements (e. g., transistors, diodes) and passive circuit elements (e. g., resistors, capacitors) are integrated into the substrate. With this technique it is possible to place a complete circuit containing both active and passive components in a case that would previously have held only one of the transistors.

Thin film circuits are formed on an inactive substrate such as glass or ceramic. The passive circuit elements are formed by vacuum deposition, chemical deposition, or electrochemical deposition, and active elements are added separately as discrete components. In the future, active elements may be formed by a deposition process.

Modular circuits consist of discrete, minute active and passive components which can be connected by wires, printed circuitry, or thin films. These are packaged in tiny modules.

There is now considerable competition between companies, company divisions, and military agencies as to which method is best. For example, the Army Signal Corps with P. R. Mallory and RCA support the modular approach. The Air Force with Fairchild, Motorola, General Electric, Westinghouse, and Texas Instruments support the integrated circuit approach.* Lear Siegler champions the thin film approach.

The accelerated development of microcircuitry, especially with respect to reliability, is a major contribution of the missile/space effort. The field is of such significance that it is safe to say that microelectronics would have evolved in the absence of missile/space support, but at a much slower pace.[4]

The computer industry will certainly benefit from the technical knowledge produced by missile/space funding. Carryover of digital transistor or microcircuit know-how into the computer field will be almost immediate. Switching circuitry developed primarily for space vehicle electronics has direct application in commercial computer circuits. Semiconductor circuitry developed for military applications could become "off-the-shelf" computer component items.

* Westinghouse champions the word "molectronics" or molecular electronics. Since there does not seem to be a universal understanding of what the word means or what the concept is exactly, it is categorized with the integrated circuit approach.

Of interest in the microsystems electronics field is the advent of new companies spawned by industries presently engaged in the missile/space program. These new companies may well be started by personnel who have essentially been educated by missile/space program funding. Techniques acquired while in the employ of a contractor to the Air Force, Navy, Army, or NASA are directly transferrable to their new company. In the past few years there have been several successful attempts of such transfer.

Examples of missile/space effort contributions to microelectronics follow.

Fairchild Camera and Instrument Corporation
Fairchild Semiconductor Division
Mountain View, California

<u>micrologic semiconductor integrated circuits</u>

The missile/space field has created a market in which Fairchild can produce sophisticated scientific products and achieve a fairly rapid payout on its investment in development. When the barrier of initial development cost, and the resulting initially high-per-unit price has been surmounted, the company expects to be able to develop a sizeable market for its products in the non-government economy. In other words, the contribution of the missile/space field has been to accelerate the development of technically sophisticated products and bring them to the non-government user more rapidly.

An example of this is Fairchild's micrologic series--a family of functional circuit elements in which transistors and resistors are diffused by a Fairchild process into a single chip of silicon. These chips of silicon are circuits themselves and can be used to fabricate a computer logic section. No other components are required.

According to Fairchild, micrologic elements make possible a simplified approach to the job of designing a computer and greatly reduce the lead time from design to prototype model. Fairchild claims that the use of micrologic elements can cut the logic system design and assembly costs by 90 percent, space requirements by 95 percent, and power requirements by 75 percent.

These elements were not designed specifically for the aerospace market. They were designed for the computer field in general. In the early stages, the cost was high, and micrologic elements found most of their usage in missile, space, and military applications. Prices recently, however, are nearly competitive with conventional construction.

Lear Siegler, Inc.
Research Laboratories
Santa Monica, California

<u>semiautomatic machine for producing thin film circuits</u>

The Research Laboratories of Lear Siegler, Inc., working on ways to mass produce thin film microcircuits, have developed a semiautomatic machine for making these circuits. The missile/space effort has contributed toward this development only in that it provides a primary market for thin film circuitry; however, without this market thin film circuitry or its mass production probably would not have reached its present level of development.

A thin film circuit is made by depositing, in a vacuum, thin film materials on a thin substrate of glass. Deposition takes place through a series of stainless steel masks so that the desired circuit elements are deposited.

The electrical resistance, and therefore the film thickness, is controlled automatically by Lear Siegler's machine. All capacitors, resistors, and interconnections in the circuit are made with thin film deposition.

An amplifying circuit using conventional transistors and diodes is built by stacking the glass slides together and making interconnections through holes drilled in the glass with ultrasonic drills. A completed three-stage amplifier measures 1/2 inch by 1/2 inch by 3/10 inch; it contains 8 resistors, 3 capacitors, 3 transistors, and 2 diodes. This technique has reduced the size of an amplifying circuit by a factor of 10. Over 50 different types of analog, digital, and radio frequency modules are being produced by Lear Siegler.

Lear Siegler will license its machine to manufacturers of electronic products. Present non-missile/space applications of the company's microcircuits include their use in autopilots, hearing aids, and commercial data transmission. The miniaturized circuits probably will find commercial use in computers due to the circuit's small size, low power requirements and high switching speeds. The company believes that replacement of resistors and capacitors by thin films, with mass production of thin film circuits, will lower the cost of electronic amplifying systems and increase their reliability.

3. Thermoelectric Refrigeration

There are two basic thermoelectric effects: the Seebeck effect discovered in 1821 and the Peltier effect discovered in 1834. The former describes electric power generation by application of heat to a junction of two dissimilar materials while the latter describes the creation of a temperature difference between junctions of two dissimilar materials by the passage of a steady electric current. Thermoelectric refrigeration, or Peltier cooling, applies the latter effect.

Thermoelectric refrigeration efficiency depends upon the Seebeck coefficient (voltage produced between junctions of dissimilar materials per unit temperature difference), thermal conductivity, and electrical conductivity. A figure of merit commonly used is the Seebeck coefficient squared, times electrical conductivity, divided by thermal conductivity. In general, the low Seebeck coefficient of metals gives a metallic junction of low figure of merit. The very low electrical conductivity of an insulator tends to give insulator junctions low figures of merit also. Semiconductors, however, have moderate Seebeck coefficients, thermal conductivities, and electric conductivities and, therefore, significantly high figures of merit. Because semiconductors had not been extensively investigated until the 1940's, Peltier cooling, as demonstrated by metals, remained a laboratory curiosity for over 100 years.

The modern pioneers of semiconductor thermoelectric research are M. Telkes and A. F. Ioffe.[5] Expansion of work in the field has been significant in recent years as several survey articles in the field indicate.[6] Demonstration of practical prototypes of thermoelectric cooling applied to large room coolers and industrial air conditioners, ice makers, water coolers, and miniature refrigerators has been accomplished by Borg-Warner, Carrier, General Electric, RCA, Whirlpool, and Westinghouse.[7]

Future applications of thermoelectric cooling will become more practical as figure of merit is increased--an increase dependent on results of semiconductor materials research. Materials research has been sponsored by companies themselves, by aerospace programs, and by other government defense spending. One noteworthy government sponsorship of both materials research and practical thermoelectric cooling is that of the U. S. Navy Bureau of Ships.[8] This work is dedicated to the discovery of noiseless and easily controllable air conditioning for submarines. Temperature control and air conditioning of aerospace vehicles is a similar problem.

Application of thermoelectric cooling in space vehicles also requires auxiliary equipment. For example, an air conditioning unit may require a controllable steady current from zero to several hundred amperes. Power probably will have to be transformed, rectified or inverted, and fed through a thermostat controlled regulator to supply the coolers. Standard commercially available relays, electromechanical controllers, and gas and vacuum tubes are not as suitable as potentially available solid state devices. Therefore, development of auxiliary control equipment as well as development of the basic coolers is necessary for practical aerospace vehicle application.

Similar control systems are necessary for many other functions of aerospace vehicles. An example is the control of orientation motors for antennas, solar cells, control fins, or guidance rockets. Much research and development to make these systems small, rugged, and efficient has already been supported by the missile/space programs. Results of this work have been applied to thermoelectric refrigeration, both for aerospace and commercial applications.

Although large thermoelectric coolers for air conditioning are potentially attractive for many applications, their expense in comparison with conventional equipment has hindered their usage--even for missile/space. On the other hand, small coolers for individual electronic components and circuits have seen extensive use in missile/space and military applications. This kind of cooler is competitive from a cost standpoint.

Problems concerning thermoelectric power generation are quite similar to those of thermoelectric cooling. Improvements resulting from semiconductor materials research will affect both applications, and developments in thermoelectric refrigeration will affect power generation and vice versa.

Examples of thermoelectric refrigeration R & D fall-out follow.

Borg-Warner Corporation
York Division
York, Pennsylvania

solid state controls for cooling systems

Borg-Warner makes commercial, military, and missile/space refrigeration equipment. While York Division feels there have been many indirect benefits from the missile/space effort, the most direct contribution has been solid state rectifiers and controls used in power supplies and inverters for refrigeration equipment, notably thermoelectric cooling equipment.

thermoelectric cooling (potential)

With regard to the thermoelectric cooling systems themselves, York Division believes that thermoelectric semiconductor materials are more a product of research in electronics than in thermoelectric cooling. Some of this electronics research may have been missile/space motivated; it is difficult to know for sure. Much of York's effort with regard to thermoelectric cooling has been toward the development of submarine cooling systems where noise elimination is a vital factor.

The application of the whole field of thermoelectric cooling to the space effort is now being studied by the company; however, little specific hardware has evolved from this branch of its total thermoelectric cooling effort.

* * * *

The Wall Street Journal notes that Borg-Warner has stated that thermoelectric cooling is now economically practical for only small units. However, military requirements have uncovered many advantages in reliability, space saving, and silent operation; ultimately there will be a savings in cost.[9]

Department of the Navy
Office of Naval Research
Washington, D. C.

Bi-Te thermoelectric junction (potential)

The U. S. Naval Research Laboratory has a long standing interest in thermoelectric devices and the Peltier effect. A circuit using a bismuth-tellerium junction was developed to regulate the temperature of a critical system component at a temperature below ambient. This development was the result of a missile/space program requirement. The same circuit can be used to maintain the component at a temperature warmer than ambient.

* * * *

This cooler could be used to temperature regulate sensitive components in commercial equipment; however, laboratory personnel are not aware of such commercial application if it has taken place.

4. Connectors, Cables, and Printed Circuits

One of the first connectors was the sleeve contact plug and matching jack, developed for telephone switchboards around the turn of the century. Since that time, many improvements have been made in design, materials, variety, performance, and appearance, but the basic need which prompted this development persists: a means to provide simple, fast, flexible, and reliable electrical connection.[10]

Many difficulties were encountered with connectors in World War II, and in the years following considerable development work has been devoted to improving all connector characteristics. Miniaturization, improved dielectrics, better corrosion resistance, better high temperature performance, and improved mechanical reliability have all been objectives of this effort.

Stringent military requirements prompted the development of the AN series of connectors, a highly developed and highly reliable connector series used widely in aircraft wiring. This series provides numerous combinations of shell types, pin arrangements, numbers of pins, inserts, and current carrying capacities. AN connectors are generally round multi-pin, multi-socket, non-radio frequency, current carrying connectors. Fewer in number, but also important, are coaxial type connectors for carrying radio frequency current, printed circuit connectors, plugs and jacks, and rack and panel connectors.[10]

All these connectors have been improved by the post World War II military effort and the subsequent missile/space effort. (See descriptions following this introduction for examples: Amphenol-Borg--An Improvement on the AN Series; Elco Corporation--Improved Rack and Panel and Printed Circuit Connectors; Microdot Inc.--Coaxial Cables and Connectors.) The missile/space program has prompted further connector development along the lines of miniaturization, reliability, resistance to breakdown in high altitudes or space, resistance to radiation, and resistance to high temperatures.[10]

Of these improvements, miniaturization and higher reliability are of the greatest commercial interest. A complex computer, a complex communication system, or an automated plant is particularly dependent on reliability of individual components for the reliable functioning of the whole system. It is evident that if the number of components in a system increases without a corresponding increase in reliability of each component, the reliability of the overall system must decrease. Therefore, continued improvement in reliability of components is essential to the construction of increasingly complex equipment, both military and civilian.

Closely related to connectors is the field of cables. Cable is constructed of one or more insulated conductors, solid or stranded, enclosed in an outer protective covering or jacket. As in the connector field, current trends in the manufacture of cable have been toward reduced weight and size, increased operating temperature, resistance to radiation breakdown, and resistance to breakdown in a high altitude or space environment.[11]

Printed circuits provide a compact, reliable means of making electrical connection. A printed circuit is a thin pattern of electrical conductors closely affixed to a supporting insulator.[12] Printed circuitry was developed in early 1945 by the National Bureau of Standards to save space in the radio proximity fuse.

Today, printed circuits are of three primary types: etched, plated, and stamped. Etched circuits and plated circuits are both formed from a copper clad laminate by a combined photographic and etching (or photographing, etching, and plating) process, whereas stamped circuits are formed from metal foil, hot-pressed with an adhesive to the insulator.

The missile/space program has relied heavily on the printed circuit because it facilitates modular design, improves reliability, and reduces weight and bulk of many complex systems. Production for the aerospace industry has given rise to more reliable and otherwise improved printed circuitry through tighter specifications, better design, improved production techniques, and the use of better materials.

Examples of missile/space related improvements in cables, connectors, and printed circuitry follow. Note that these do not represent real innovations or radical changes, but are primarily improvements.

Amphenol-Borg Electronics Corporation
Amphenol Connector Division
Chicago, Illinois

<u>48 Series connectors</u> About 1954, the Air Force contracted with Amphenol to develop a new line of connectors which would eventually, in the company's opinion, supersede the old AN series. Before the line was completely developed, Air Force funding ran out, and the company decided to finance completion of the program itself. Amphenol believes that missile and jet aircraft needs were a part of the original Air Force motivation for funding the program.

Amphenol's motivation in continuing development without Air Force funding was the belief that the old AN series would be partially phased out. During the latter phases of this development, the Air Force began to regain interest, and further specification requirements were forthcoming.

During the development period, the missile/space program effort was accelerated, which caused some basic changes and necessitated the redesign of the entire connector. The line of connectors which finally ensued (military specification MIL-C-26500) is called the 48 Series by Amphenol and was introduced in 1961. This line combines advances in materials technology for high reliability under extreme conditions with a simplified mechanical design that reduces the overall connector harness and assembly cost.

The 48 Series connectors are utilized extensively in the Minuteman missile program, "Looking Glass" B-52 Retrofit program, "Pipe Cleaner" B-47 Retrofit program, F-100 fighter program, and checkout equipment for doppler radar. Other programs under development likely to use MIL-C-26500 connectors include Madrac, Dyna-Soar or X-20, C-141, Pratt-Whitney TFX engine, Polaris, Agena, Snap-Shot, Sergeant, Titan III, and two classified projects not identified.

Commercially, the connectors are used on the Boeing 727 jet aircraft, and Amphenol-Borg anticipates the use of the 48 Series connectors on other jet aircraft in the future.

The company notes that non-space use of MIL-C-26500 connectors (its 48 Series) will probably be limited. By its very nature, the connector was designed to satisfy stringent environmental conditions requiring a high degree of reliability. Non-space applications do not normally involve such demands. Other types of connectors available, in many cases, will satisfy non-space requirements at less cost. The company adds, however, that knowledge resulting from development of its 48 Series has proven valuable in developing other connector lines--up-graded versions of standard lines more suited for commercial applications.

* * * *

(Several other firms are now manufacturing connectors which meet or are similar to the MIL-C-26500 specifications.)

Brown Engineering Company, Inc.
Huntsville, Alabama

<u>printed circuit board connector</u>
(potential)

Brown Engineering Company is producing a connector which makes circuit connections between two printed circuit boards without solder joints. A means of connecting printed circuits which would withstand great vibration, permit dense packaging, and insure reliability was needed for missile/space vehicles. Connectors which would perform satisfactorily were not readily available. As a result, the connector now being produced by Brown was designed.

The actual relationship involved in the development and production of this connector is slightly different from that normally occurring under NASA contracts. The basic connector concept was developed by an employee of the Marshall Space Flight Center of NASA at the time that this organization was a part of the Army. A patent application was filed by the Army Patent Office in this employee's name, it being determined that the patent rights for the invention, with the exception of a royalty-free license retained by the Government, would remain with the inventor. The patent is still in process at the U. S. Patent Office. Brown Engineering Company has an exclusive license agreement with the inventor to manufacture and sell the connectors.

The connectors were further developed by Brown Engineering with its own funds under the license agreement and appear to be the answer to many connector problems. They are currently being used in the Pershing and Saturn missiles.

The connectors are presently being evaluated for use in commercial digital computers, which represent the principal potential non-space market.

Elco Corporation
Philadelphia, Pennsylvania

<u>Varicon connector</u>

Elco's basic product is called the Varicon connector. It works by the interlocking of two forked metallic strips which form a four-sided electrical connection with constant mechanical pressure on each of the four sides. The product was developed about twelve years ago by the president of Elco as a competitive variation on the standard rack and panel connector. Many variations have been made on the basic connector itself and in geometrical arrays of these connectors.

From the inception of this connector, many improvements have been made; a number of these can be traced to the company's work with the missile/space industries. (When a series of improvements have been made in the product, as has happened with the Varicon contact, the events blend into a continuous spectrum of improvement. It is not practical to identify each improvement and its cause. It is more meaningful to identify the overall change and the overall causes of this change.)

One of the most important overall changes in the Varicon contact was the miniaturization of the product. Other changes in materials, tolerances, and methods of terminating the cable in the connector (wrapping or crimping, rather than soldering), have made a more reliable product. Finally, the product line has been expanded from the original rack and panel concept to printed circuit connectors and micromodular connectors. Although the company has always had commercial sales of its product, it feels that recently the missile/space effort has been the prime impetus behind the continued improvement in reliability and continued miniaturization of its product. Varicon connectors have been used in the Titan, Minuteman, Atlas, Hawk, and Polaris missile programs, as well as for NASA's Mercury and Mariner.

Non-missile/space uses of Varicon connectors include their incorporation into: commercial data processing equipment, vote tallying equipment, navigation equipment, FAA communications equipment, radar equipment, digital voltmeters, and airborne power supplies. Of all the effects of the missile/space program on Elco's products, the company thinks the following two are of prime commercial importance: 1) the reliability has been improved, important in complex commercial systems and, 2) commercial users can obtain this reliability at relatively little or no extra cost.

Epsco, Inc.
Cambridge, Massachusetts

<u>high quality printed circuit boards</u>

While working on the Polaris missile program, Epsco had a requirement for a high quality printed circuit board. They were not able to purchase commercially the kind and quality of board desired. Therefore, the company developed its own for use in the program. From this development, the company became established in the production of printed circuits which they now sell commercially as well as for military and space applications.

Approximately 25 percent of the sales are for non-space use.

International Resistance Company
Plastic Products Division
Philadelphia, Pennsylvania

<u>Polystrip(R) and Lamoflex(R)</u>

Polystrip is a thin, flat, flexible cable containing rectangular conductors protected between tough plastic sheets. The two-dimensional characteristic of the harness provides advantages in installation, electrical characteristics, ultimate package size, and weight. Furthermore, the flat configuration of the conductors allows materially increased current capacity (up to 200 percent) as compared to round wire and cable.

Lamoflex is thin, flexible etched circuitry or cable. The circuits are sandwiched between two sheets of thermoplastic material which is fused into a homogeneous material. Circuit layers can be stacked. Four-layer circuits are in high volume production, and six-or-more-layer circuits are in the prototype stage. These products withstand flexure, vibration, humidity, salt spray, and chemicals.

Polystrip and Lamoflex were initially marketed by IRC several years ago. The motivation for the original development of these two product lines was to provide interconnection materials appropriate for the new requirements of miniaturization and weight reduction in the electronics industry, which were accelerated by missile/space specifications. Polystrip and Lamoflex have been used in the Minuteman, Subroc, and Atlas missile programs and the Tyros, Echo, and Orbiting Solar Observatory satellite programs.

Although the majority of uses of Polystrip and Lamoflex have been in connection with the missile/space program, new applications are developing in commercial computer, communications, and appliance equipment.

Sanders Associates, Inc.
Nashua, New Hampshire

Flexprint(R) Sanders makes a flat, flexible printed wiring called Flexprint circuitry. Flexprint circuits are flexible etched printed harnesses and circuits used for interconnection, differing from hardboard printed circuits in that they may be flexed, folded, fitted in any dimension or preformed. At Sanders, the development of Flexprint wiring started with a missile application. Its value in a multitude of commercial and industrial applications became quickly evident. About three years after the original missile work, Flexprint was introduced to the general market. It has been sold to manufacturers of computers, telephone systems, and photographic equipment.

* * * *

A new products article in The Engineer states that a British firm, Technograph Electronic Products, Ltd., is making a cable similar to that of Sanders and International Resistance Company. This product consists of light, flexible strips of copper sealed between layers of melamine plastic. It has great flexibility over the temperature range minus 70° to 140°C. The tensile strength is 500 pounds per square inch. The electric properties of this cable are unaffected by folding or bending, and the cable is highly resistant to fungus, sunlight, salt water, acids, alkalies, and alcohol. Reductions in cable weight and bulk of up to eighty percent are claimed with this product.[13]

Tri-Plate(R) Sanders also markets Tri-Plate microwave strip transmission line, a printed microwave circuitry which replaces coaxial or waveguide media with a substantial reduction in size and weight. The development of Tri-Plate at Sanders started with a missile application. Current missile/space applications of Tri-Plate include its use in missile and satellite communications and control. Commercial applications include aircraft, point-to-point communications, navigation, and high speed computers.

* * * *

The use of planar or microstrip transmission lines was first explored during World War II. This development remained relatively unknown and unpublished in the early post-war period.[14] During 1952, work was done by the Federal Communications Laboratories in studying and improving microstrip. Grieg and Engleman investigated two basic types: 1) a cylindrical conductor suspended above a ground plane and, 2) a narrow ribbon conductor (microstrip) separated from the ground plane by a dielectric material. The microstrip was found to be superior to the cylindrical conductor because the field spread around the conductor is small, making compact packaging possible. Printed circuit techniques are applicable to the construction of microstrip.[15]

California Institute of Technology
Jet Propulsion Laboratories
Pasadena, California

potted connector

Under the Army's Sergeant missile program, improved potted connectors were developed at Jet Propulsion Laboratories which are now being sold commercially by one of the persons originally connected with the program. A potted connector is simply a standard connector encased in a rubber or plastic resin to give it rigidity and protect it from moisture and other damage.

Lockheed Electronics Company
Plainfield, New Jersey

printed circuit facility

Lockheed Electronics' Avionics and Industrial Products Division has built a large printed circuit facility mainly for the purpose of supplying printed circuits to the missile/space industry. Currently, 25 percent of the sales go to non-missile/space users and this percentage may eventually climb to 50 percent. (Although in some cases, the end user is still the government.)

Missile/space requirements did not create printed circuits but printed circuit production and technology have been given a tremendous boost by them. Lockheed's facility and products made there are examples of that impetus.

Pacific Automation Products, Inc.
Glendale, California

electronic cable

(potential)

Pacific Automation's main product line, electronic cable, is based on a long history of electric cable development. However, the complexities of missile/space systems, the short product development lead time, and the requirement for higher reliability have forced improvement in manufacturing techniques and overall product improvement. The improved cables are used in launching sites, propulsion test facilities, tracking stations and, to a lesser degree, in the space vehicle itself. The company considers it highly probable that its improved cables will ultimately find use in industry. The first use probably will come in the field of automation, since reliability is critical to the complex automated factory.

All product development has been funded by the company, with the exception of a few specialized cables for two Air Force programs.

Microdot Inc.
South Pasadena, California

miniaturized cable and connectors

Microdot was incorporated in 1950 to produce miniature cable and connectors for hearing aids requiring more reliable, smaller components. However, this market was limited and, in 1953, the company decided to pursue the emerging missile/space and related electronics market. By the end of 1953 it had developed a proprietary line of miniaturized coaxial connectors. Related cable was purchased by the company from cable manufacturers. Between the years 1953 and 1961, Microdot expanded its product line to include multipin coaxial and multi-pin power connectors, solderless crimp-type coaxial connectors, coaxial switches, and some types of transducers. In addition, having found cable purchased from other manufacturers to be inadequate, the company developed its own cable. Called "Mini-Noise," its cable is designed in such a way that self-generated noise (from cable movement or vibration) is dissipated.

The missile/space effort has had two important effects on this company. First, it has provided the largest single market for the company's products, and second, the rigorous requirements of the industry (such as MIL-C-26500 requirements on the AN connector series) have forced continuous improvement in the reliability of Microdot's products.

In the missile/space industry, Microdot cables and connectors are being used in space communication systems, space telemetry systems, radar tracking systems, and ground test equipment. One example: the cables and connectors which linked the sensors on John Glenn's body to the telemetering equipment were Microdot products.

Outside the aerospace industry, the company's products are being used in communication systems, computers, and industrial research and test programs, again partially because of the reliability, miniaturization, and low self-generated noise of Microdot's products.

5. Display Systems

The term "display systems" is used here to refer to systems or devices which present information visually. Several display systems evolved or were improved with some contribution from the missile/space effort. However, both the types of display systems noted and the missile/space connection of these systems were so varied as to prohibit a state-of-the-art summary of the category "display systems." Examples follow.

Aerojet-General Corporation
Astrionics Division
Azusa, California

lenticular screen

(potential)

Scientists at the Aerojet Astrionics Division have developed a lenticular (made of many lenses) screen, which the NASA Ames Research Center uses with a TV projector for simulating the "outside world" as viewed by the crew of supersonic aircraft or spacecraft.

It works on the principle that most of the light projected on the screen is focused and reflected back over a narrow angle. Therefore, a very bright picture image is obtained over a narrow field sufficient for crew-training purposes. Thus the screen can be used for movie or TV projection when the available projection intensity is much lower than normally required. An interesting feature of this screen is that pictures from two or more separate projectors can be shown on it, and the viewer will see one or the other depending on where he stands.

The idea originated in connection with simulation for aircraft flight and gunnery training, but is being refined considerably in view of potential applications in the manned space program. An advanced version, of potential commercial importance to the entertainment industry, is under development. It uses new principles to provide wider viewing angles and much greater suppression of ambient light.

Radio Corporation of America
Astro-Electronics Division
Hightstown, New Jersey

<u>photo-dielectric tape</u> (potential) — A photo-dielectric tape representing a new type of image-sensing device is under development at RCA's Astro-Electronics Division for use in satellites and space vehicles. The system offers several advantages over existing photographic or television techniques.

Because an optical image is stored by converting it into an electronic charge pattern which can be read out directly as a video signal by an electron beam, the system has an inherently high resolution. Moreover, the system shows promise of expanding the useful part of the radiation spectrum, giving better sensitivity than standard photographic techniques.

Readout of the same image numerous times does not seriously degrade the image quality; however, the tape can be erased completely by flooding it with electrons. A high vacuum is essential to the operation of the system; thus it is well suited for operation in space. Furthermore, it is almost unaffected by radiation.

Due to its high resolution properties, this tape, or a modification of it could find use in analog or digital data handling or processing systems.

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For additional information see "Data Acquisition and Transmission," <u>Electronics</u>, <u>34</u> (November 17, 1961), p. 103; or "Electronic Space Camera Under Development," <u>Journal of the Franklin Institute</u>, <u>268</u> (December 1959), pp. 523-4.

<u>TV editing system</u> — The same division at RCA worked on the development of a computer system for cataloging pictures from the Tiros satellite. In effect, the operator would specify a certain date and time, and the proper picture was displayed on a screen.

From experience gained on this project, RCA was able to develop a system for NBC to display, edit, and splice television pictures. The project was funded in-house.

Hughes Aircraft Company
Fullerton, California

Electrocular (potential) Hughes has recently developed a small, light weight, head mounted, cathode ray tube display. The display consists of a small cathode ray tube (one inch in diameter), a single front surface mirror, an adjustable focusing lens, and a reflecting eyepiece, all of which are housed in a special tubular enclosure. The entire configuration weighs thirty ounces. The observer is presented with a monocular virtual image of the display information, superimposed upon the ambient background. The device is called Electrocular (pronounced ee-lec-trock'-you-lar). The company believes the device has application in five principal areas:

1. In space exploration, the device can be used to give an astronaut computer data, instrument data, or other television data without necessitating undue movement on his part. In many situations, the astronaut will be in a restricted postural position or an environment (zero gravity or vibrational) which will limit his ability to monitor data and instruments. This device will increase the amount of information an astronaut is able to monitor at any one time.

2. The device has potential in the Army, Navy and Air Force. For example, naval officers would not need to return to the fleet's display center to obtain revised visual briefings during rapidly changing battle conditions. Pilots could divide their attention between watching their instruments and viewing the airborne traffic pattern ahead.

3. In commercial aviation, air safety could be enhanced by the application of the device in aircraft being operated around congested airports.

4. In industry, assembly workers wearing Electrocular devices can receive instructions on wiring and installing components in complex systems, eliminating blueprints or printed instructions. This device would also aid engineers or assembly workers who must adjust equipment by consulting instruments beyond their area of vision.

5. In medicine, the device could aid a surgeon by allowing him to instantly detect any change in the patient's condition, e.g., pulse rate.

The most significant missile/space contribution to Electrocular has been creation of a market potential for the device, thereby encouraging its development at this time.

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Hughes has indicated that the display has been worn by operators for up to three hours without discomfort, but considerable psychological testing will be needed to determine operator efficiency in handling superimposed images.[16]

According to Business Week, Hughes expected to start production by late 1962. Prices will range from $300 to $700, depending on the auxiliary equipment purchased. Electrocular is one of a series of display devices developed by Hughes under company sponsorship in its Systems Laboratory in Fullerton, California.[17]

Lear Siegler, Inc.
Electronic Instrumentation Division
Anaheim, California

improved video systems — The Electronic Instrumentation Division of Lear Siegler, Inc. produces an established line of commercial and military equipment with emphasis on video systems (closed circuit TV for surveillance). The company reports that this equipment has been improved for requirements of NASA space and DOD missile programs. Lear Siegler TV cameras of extremely rugged construction have been used by NASA and the Armed Services, as well as commercially. For example, Lear Siegler produced the missile-borne TV system used by NASA on "Project Big Shot," and developed slow scan techniques which culminated in the slow scan camera used aboard the Atlas Centaur test vehicle May 8, 1962.

The company's closed circuit TV systems commercial applications include schools, industrial plants, and hotels.

TelePrompTer Corporation
New York, New York

integrated audio-visual systems — TelePrompTer Corporation designs and installs audio-visual systems for information display and presentation. Major features of its system include: integration of various audio-visual media including television, moving pictures, slides, and tape; contiguous multiple screens for display of related information; random selection of stored material; or automatic pre-programming.

The integrated system concept evolved from an assignment to provide audio-visual support to the training program at Ordnance Guided Missile School in 1958. Subsequently, TelePrompTer installed systems at the Air Force Command Post, the Navy Space Orientation School, and at NASA installations in Washington, Cape Canaveral, and the Manned Spacecraft Center at Houston.

Non-missile/space users of systems incorporating the principles developed at OGMS include: University of Wisconsin, Chicago Teachers College, Rensselaer Polytechnic Institute, American Airlines, Tennessee Gas Transmission Company, and Humble Oil and Refining Company.

6. Miscellaneous

Examples of miscellaneous electronic components or systems which incorporate missile/space contributions are:

Aerojet-General Corporation
Power/Equipment Division
Azusa, California

brushless alternator (potential) — Brushless alternators come in many forms; all are similar in that the "brush" common to most electric motors and generators is eliminated. Advantages of brushless operation include: low maintenance, high reliability, and absence of brush and commutator sparking, making it adaptable to operation in an explosive environment.

A brushless alternator was developed at Aerojet's Power/Equipment Division because of a requirement for reliable rotating auxiliary power sources, mainly in the missile/space field. The alternator was improved as a result of projects in the following areas: space power systems, mobile ground nuclear power plants, torpedoes, pilotless aircraft, and battle tanks. The physical layout and electrical design features of Aerojet's alternator are considered proprietary. It can be said, however, that the only rotating part is a solid metallic disk (field) which contains no winding. The field polarity is electromagnetically induced through the use of stationary field coils.

Brushless alternators, although not of the same type as Aerojet's, are now substituted for generators in some automobiles. The Power/Equipment Division feels that improvements in brushless alternators resulting from missile/space work will very probably have commercial carry-over.

International Resistance Company
Burlington Division
Burlington, Iowa

International Resistance Company has developed several types of resistors to meet various specifications of the missile/space program. It believes all may have commercial potential.

MMF

(potential)

The first is a microminiaturized, precision, metal film resistor (MMF). Production techniques for this resistor are essentially the same as those used by International Resistance Company for several years to produce its line of evaporated metal film resistors. The unique characteristic of the MMF is its miniature size, developed for missile/space requirements. (It is 0.105 inch long by 0.045 inch diameter; power rating is 1/20 watt at 125°C; resistance range is 30 ohms to 100K ohms; temperature coefficients available are 0 ± 50 PPM/°C, 0 ± 100 PPM/°C, 0 ± 150 PPM/°C.)

Programs utilizing MMF include Nike-Zeus and Telstar. The company believes that MMF could be used to advantage in portable commercial or industrial electronic equipment and computers of all types.

XLT

(potential)

Another major product is a series of highly reliable resistors called XLT Precision Film Resistors. Development of this series of resistors was initiated for the Minuteman program. It was undertaken after an analysis by the prime contractor revealed that a two order of magnitude reliability improvement in resistors was needed to meet Minuteman requirements. Requirements called for a resistor with a failure rate below 0.0004 percent per thousand hours, proved to a high confidence level. Failure in this case is defined as change in resistance greater than 0.5 percent. This objective has been achieved.

Manufacture of the XLT takes place in a precisely controlled environment. A punched card issued with each resistor documents that resistor's performance in each of many tests and measurements.

Programs other than Minuteman which have used or will use XLT resistors include: Midas, Advent, Nimbus, OAO, and Mariner.

International Resistance Company anticipates that XLT resistors, or the techniques used in making XLT resistors, will find future non-missile/space applications by providing uninterrupted resistor service in vital electronic systems without resort to expensive redundancy or ultra-conservative derating of components. The economic justification for the higher initial cost of these resistors lies in the fact that through the use of such parts, the overall cost of the systems is reduced.

Development of the MMF resistor was funded by the company. Development of the XLT was funded by the Air Force through a subcontractor.

International Telephone and Telegraph Company
ITT Federal Laboratories
Nutley, New Jersey

electronic scanning star tracker (potential)

Conventional star trackers for space vehicles present several serious problems: 1) In a rotating device, conventional bearings cannot be used without allowance for lubricant evaporation. 2) Precise control of vehicle attitude requires removal of the angular momentum given to the vehicle by a rotating device, and thus the expenditure of more energy. 3) Vibration generated by the scanning motor can limit the angular resolution of the tracker.

These problems prompted development at ITT Federal Laboratories of an electronic scanning star tracker, utilizing a special ITT multiplier phototube. Potential commercial applications include celestial tracking in ship navigation and utilization of the tracker's high electro-optical sensory accuracy in automation servo control systems, e.g., milling machines.

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For additional information see William D. Atwell, "Star Tracker Uses Electronic Scanning," Electronics, 33 (September 30, 1960), pp. 88-91.

P. R. Mallory and Company, Inc.
Indianapolis, Indiana

tantalum capacitor

The concept of using tantalum (with its high dielectric constant) for a high capacitance to volume capacitor was postulated over 25 years ago by P. R. Mallory. Development began after World War II under Air Force sponsorship and has continued since, stimulated by Air Force funding and general governmental needs for small capacitors to operate in a space or military environment. Tantalum capacitors developed under this stimulus have been used in industrial communications equipment.

A more specific example is a government supported program for development of miniature, highly reliable, solid tantalum capacitors for missile/space use. To date the program has not provided the quality capacitor required by the government. It has provided a tantalum capacitor of sufficient quality to be adapted to hearing aids of smaller size and lighter weight.

Sprague Electric Company
North Adams, Massachusetts

capacitor reliability

One of the largest contributions of missile/space R & D at Sprague has been in the area of reliability. Highly reliable parts have been developed through Sprague sponsored research as well as through cooperative programs with the Department of Defense. In many instances the improved techniques and processes developed for missile/space have been adapted to standard commercial production. For example, the reliability of the Sprague 150D solid tantalum capacitor, applied in a 25-capacitor system, has been improved five-fold since January 1960. These units are widely used in such everyday products as hearing aids, miniature transistor radios, aircraft control systems, guidance systems, and medical instrumentation.

McGraw-Edison Company
Bussmann Manufacturing Division
St. Louis, Missouri

fuses and protective devices

Bussmann manufactures fuses and protective devices. In most cases, its fuses or protective devices used in the missile/space program are modifications of a commercial product, manufactured to more rigid specifications to give greater reliability. Production controls, which Bussmann has been forced to adopt to meet these specifications, have made it possible for the division to produce, at a reasonable cost, products which were considered laboratory oddities prior to the missile/space program.

For example, the development of hermetically sealed fuses in subminiature dimensions resulted directly from the missile/space program. These have found use in protection of military and commercial computer circuits.

Phillips Control Company
Joliet, Illinois

miniature rotary relay

Phillips Control Company has been in the commercial and industrial relay business for 17 years. During this time it has developed many commercial telephone and power type relays. During 1961-62, the company increased its efforts to meet military relay specifications calling for more rigid electrical and environmental requirements. These efforts have resulted in a two-pole, double-throw, miniature, rotary, electromagnetic relay, designed as a rocket or space vehicle component as well as for use in ground support equipment.

The relay's present non-space applications are limited mainly to the aircraft industry and the miniaturized electronics field. The company believes future uses will include the commercial and industrial control field.

The development of this product was funded by Phillips Control Company.

Tung-Sol Electric, Inc.
Chatham Electronics Division
Livingston, New Jersey

DC power supply — A DC power supply (or converter) converts an AC input to a regulated DC output. Chatham Electronics, relying on its background in building aircraft power conversion equipment, designed and built the central power converter for the Boeing Bomarc B missile. Specifications for this converter, called the 28VCP-C, were beyond current state-of-the-art capabilities. Circuits had to be redesigned and the unit transistorized to make a more compact, reliable power supply.

Chatham has taken the ideas developed in the 28VCP-C program and designed a new commercial power supply for laboratory use called the R2432-100. This device, designed for general use by aircraft, missile/space, and related electronics industries, has been sold for use in laboratories, production lines, and ground maintenance equipment. (The commercial use to date includes only the aircraft industry. The supply operates in the 28 volt range, which is the operating voltage of aircraft and missile systems.) Since development of the R2432-100, other power supplies have been designed using 28VCP-C principles. Several have found commercial use.

Funding for the 28VCP-C came from Boeing and Chatham. Commercial development of the R2432-100 and related items will continue to be funded by Chatham.

Specifications of the R2432-100 are as follows: AC input--200-240 volts at 58-62 cps; DC output--24-32 volts at 0-100 amperes. Chatham lists the major advantages of the R2432-100 as: 1) weight less than half as much as similar products, 2) one-quarter the size, and 3) more economical.

Lockheed Electronics Company
Plainfield, New Jersey

recorders — Lockheed Electronics was awarded a NASA contract to develop and standardize a modularized tape transport for satellite use. Partially as a result of background knowledge gained, Lockheed is developing a line of commercial recorders. Anticipated customers include the automotive industry for strain gage recording, the geophysicists for seismic recording, and laboratories in general for use with test equipment. These recorders have recently been placed on the commercial market and a few units have been sold.

Allied Research Associates, Inc.
Boston, Massachusetts

Bartlett/Green cigar sorting machine — A colorimeter has recently been developed by Allied Research Associates which automatically sorts cigars for uniformity of color. The development of this specialized device was an industry-funded project. However, its development and marketing at this time were made possible largely through knowledge of solid state physics and printed circuitry gained through participation in missile/space programs.

One of these devices is now in use, and additional units are being offered at a price of approximately $100,000. The company will tailor each device to suit customers' specifications. A similar device still in development is being adapted to monitor the color of cloth as it is being dyed. The machine is named after its developers at Allied Research.

C. CONTROL SYSTEMS

1. Gyroscopes and Inertial Guidance

Inertial guidance is the process of navigating a vehicle with reference to a particular starting point by accurately measuring changes in velocity (accelerations) and time, then transforming these changes to a three coordinate system to determine the position traveled from that starting point. The essential parts of an inertial guidance system are: gyroscopes (gyros), accelerometers, and a computer. The gyros function to establish a set of three dimensional coordinates, fixed in space, independent of rotational motions of the earth or the vehicle. Any change in angular position (rotation of the gyro system) is sensed by the gyros, and servomechanisms are used to restore the system to its original position. In other words, any torque, however small, which acts to change the position of the gyro system is detected. A counterbalancing torque is then applied by the servomechanisms.

The accelerometers, then, aligned in space by the gyros, detect any change in linear velocity of the vehicle. Changes in motion or acceleration are detected in all three directions of the particular three dimensional coordinate system chosen. These data are twice integrated with respect to time to get net distance traveled in all three directions--the position of the vehicle with respect to its starting point. This information, plus a knowledge of distance and direction to the destination, is all that is needed for precise navigation.

The computer system takes the data from the other inertial instruments as input, makes computations, and supplies the necessary output to correct errors in the flight path of the vehicle. (Computers in general are discussed in Part 2 of this section.)

Performance specifications for the guidance system depend on the length of time the system must rely on purely inertial reference and on the dynamic range over which acceleration must be measured. Therefore, a missile system is not directly comparable to a shipborne system, for the missile system is subject to a far greater range of acceleration and must be in operation for a much shorter time than the shipborne system. However, whether the system be designed for a missile, aircraft, or submarine, the accuracy requirements on both accelerometer and gyro are extreme.

The gyroscope is an instrument comprised of a high speed rotor supported by a sytem of gimbals. A device of this general nature was first used in 1852 by L. Foucalt, a French physicist, to demonstrate the rotation of the earth. The device remained a laboratory curiosity until late in the 19th Century when G. M. Hopkins introduced the first electrically driven rotor. Dr. E. A. Sperry became interested at the beginning of the 20th Century and continued developmental work. In 1908, Max Schuler of the Anshutz firm of Germany developed the first practical marine gyrocompass (see improved gyrocompass examples following this introduction), refined by Dr. Sperry and in wide use today on large ships. Sperry also developed a family of gyroscopic instruments for aircraft use. During World War II, gyroscopes were used in the stabilization of naval guns, greatly increasing their accuracy.[1]

However, the demands of the space era, beginning with the use of basic guidance principles in the German V-2 rockets, have led to the rapid evolution of inertial guidance and to several order of magnitude improvements in gyros and other components comprising an inertial guidance system. In the United States in 1945, Dr. C. S. Draper and colleagues at the M. I. T. Instrumentation Laboratories began investigating basic problems involved in design of accurate and stable inertial guidance systems. Most of the principles employed in today's inertial guidance systems were being used in the mid-1950's. In 1953, for instance, the first inertially guided coast-to-coast airplane flight was made under the direction of Draper and his group. Other groups working concurrently on the problem included the Autonetics Division of North American Aviation (see North American Aviation statement immediately following this introduction) and the Army Ballistic Missile Agency.[1]

Many problems had to be overcome before missile inertial guidance could become a reality. One of the most important relates to a phenomenon associated with gyros called "precessing." A rotor with high angular momentum, as that used in a gyro, reacts to any torque acting on the rotor axis by precessing, or turning about an axis perpendicular to both the rotor axis and the axis of the applied torque. This phenomenon is one of the most useful characteristics of a gyro, but also the source of many of its inaccuracies.

Unwanted sources of torque which will cause the gyro to precess include: frictional drag imposed by the system used to conduct power to the rotor; frictional drag of the gimbal support bearings; and torque imposed by the altitude sensing system.

At the end of World War II, the inaccuracy caused by undesirable precession was enough to result in an error in ICBM missile guidance of 1,000 miles or more at the target. In contrast, for many applications a miss of one mile at the target may be taken as the acceptable limit of uncertainty.[2] Therefore, gyro errors had to be reduced by several orders of magnitude. To illustrate acceptable error, undesirable torque had to be reduced to 73 thousandths of a dyne centimeter. Furthermore, the deviation of the center of mass of the gyro from the gyro axis could not average more than one ten millionth of an inch--a distance less than about 15 crystal lattices of materials commonly used to construct the gyro unit. Adding these constraints to the requirment that gyros operate under shock and vibration, makes the progress in recent gyro development seem impossible. However, acceptable drift rate--that rate which would cause an uncertainty of about one mile at the target--is about 1/60 of a degree per hour.[2] Random drift rates of 1/200 of a degree per hour or lower are now being maintained with some of the better gyros.

A great advantage of inertial guidance for military systems is its independence from ground radio. Entirely self-contained, it is not subject to radio interference (jamming), nuclear radiation, or weather disturbance.

In the past decade, a science of inertial guidance has emerged and working systems have been engineered due primarily to the impetus of the missile/space effort. In turn, there have been these non-missile/space effects: 1) Inertial guidance systems have been made technically and economically feasible for many types of military aircraft and marine vehicles. Application of inertial guidance on future commercial supersonic aircraft is anticipated. 2) The components of inertial guidance systems have been vastly improved and are available for other uses. The most significant example is the gyro which is being used in improved gyrocompasses. The search for improved bearings has led to new types of gyros. For example, rotors are being supported on gas bearings.[3] The Sperry Gyroscope Company of Sperry Rand has developed a fluid gyro which uses a spinning fluid rather than a spinning rotor. Techniques such as electromagnetic or electrostatic supports and the use of spinning atomic particles or vibrating crystal lattices are also being studied. 3) In striving for increased accuracy, the need for highly stable engineering materials has accelerated basic research in metallurgy to investigate and reduce creep phenomena and thermalgradient effects, in which changes in the crystal structure of a metal can cause troublesome shifts in the delicate balance of gyro rotors and support members. L. R. Gohre comments that the strides in accelerometer development are not due to new concepts of accelerometer principles but result from basic research in chemistry and metallurgy which provides better alloys, fluids, potting compounds, dielectric materials, and bearing steels.[4] Certainly, some of the fruits of this research will have application outside the missile/space field.

Examples of missile/space contributions to developments in this field follow.

General Precision, Inc.
Tarrytown, New York

inertial guidance (potential)

Research performed by General Precision, Inc. in the field of guidance, prompted largely by the missile/space effort, has led to significant improvements in both gyros and inertial guidance systems. In addition to research leading to improvements in mechanical gyros, the firm is doing considerable research on bearingless gyros such as: the spinning atom, phase relationships in a laser, and on spinning objects suspended in a vacuum by the field from a superconducting magnet.

Most commercial aircraft use gyros which the company believes should benefit from improvements in this field. Most supersonic aircraft, military and proposed commercial, use inertial guidance systems and should also benefit from this research.

Litton Industries
Guidance and Control Systems Division
Woodland Hills, California

inertial guidance (potential)

The accuracy of inertial guidance systems has greatly increased recently while weight and volume have drastically reduced. For example, an inertial guidance system developed in 1956 for the Atlas ICBM weighed more than 1,000 pounds. A system performing the same functions with superior accuracy and weighing less than 30 pounds is now in advanced development at Litton.

The principal use of most Litton inertial guidance systems is on fighter aircraft of the U. S. Navy and various NATO countries. The inertial navigation system enables a fighter to accurately locate targets under any conditions of weather, during electronic interference or nuclear disturbance, and to fly a precise path back to its home base. Litton expects to see increasing use of inertial guidance on supersonic aircraft, both military and proposed commercial.

Missile/space transfer to Litton has been in the form of utilization of the same basic principles of missile systems, not in the form of spill-over of specific devices.

Sperry Gyroscope Company
Division of Sperry Rand
Great Neck, Long Island, New York

inertial guidance (potential)

Techniques learned in building inertial platforms, accelerometers, and gyros will definitely have commercial transfer in the opinion of Sperry Gyroscope. Inertial guidance work of the company has been funded primarily by the Air Force, but Sperry has also received some Navy and NASA funds to supplement developments undertaken with its own funds.

Inertial platforms have several commercial advantages: 1) They require no ground radio net, which results in substantial system cost savings. 2) They are more automatic than the aircraft guidance systems in use today. 3) Being automatic, their reaction time is faster than systems in use today. 4) They are a necessity in polar or supersonic flight. Furthermore, due to missile/space R & D, inertial platforms are becoming price competitive. Inertial guidance owes most of its accelerated development to missile/space programs.

North American Aviation, Inc.
Autonetics Division
Downey, California

The development of "Navan" gyros was started seventeen years ago by North American's Autonetics Division for use in the guidance system of the Navaho missile. These same gyros were later used in the inertial guidance systems of the Navy's atomic submarines. (The recent subpolar explorations used these inertial systems. It is interesting to note that atomic submarines employ three separate inertial guidance systems; each serves as a check on the accuracy of the others.)

gyrocompass

Using the same type gyros, Autonetics has developed ABLE (Autonetics Baseline Equipment). ABLE is a precision gyrocompass, accurate to less than 30 seconds of arc, which finds true north by sensing the earth's rotation. Autonetics has also developed a miniaturized version of ABLE called MABLE, accurate to within 60 seconds of arc. This system goes into the field on a one-man backpack, complete with its own power supply. Both of these systems are presently used primarily for military purposes (orientation of missile launchers, artillery, and mobile radar) but use is anticipated in general surveying applications.

Astro-Space Laboratories, Inc.
Huntsville, Alabama

spinning sphere gyrocompass (potential)

A new type of gyrocompass was developed by Astro-Space, called the "Spinning Sphere Gyrocompass."

A solid sphere is supported by a gas bearing and rotates with its housing. Acting as a space-fixed gyro, the sphere tilts to the west relative to the earth. The drag torque caused by the viscosity of the supporting gas restricts the tilt angle of the sphere to a fixed value. A mirror on the sphere allows the readout of the tilt direction. The instrument has a very short readiness time and is insensitive to vibration and linear acceleration.

The development of this gyro was based on knowledge of gas bearing and gyro technology accumulated over several years by Astro-Space Laboratories. It was funded by the company but the missile/space programs, providing the largest market for this instrument, supplied much of the impetus for its original development.

This gyrocompass is also designed for use as a portable surveying instrument. It is expected that when large scale production of the instrument is started, commercial customers such as oil companies will find use for it.

Department of the Navy
Office of Naval Research
Washington, D. C.

gyrocompass — The ADVENT/SYNCOM space programs created a requirement for a more accurate gyrocompass for their tracking systems. The resulting gyrocompass has present and potential shipboard use in navigation. Development, funded by the Department of Defense, was the result of combined efforts of the Bureau of Ships and Sperry Gyroscope Company.

International Telephone & Telegraph Company
Federal Laboratories
Nutley, New Jersey

gas bearing gyro (potential) — The gas bearing supports a shaft by a gaseous fluid film rather than a viscous fluid or solid bearing. The result is an almost frictionless bearing.

Development of a gas bearing gyro at ITT was sponsored by Jet Propulsion Laboratories for use as part of a space vehicle guidance and navigation system. Potential non-space application is in aircraft inertial guidance systems, where gyro precision is critical. It may also find application in surface navigation where small, light weight, high accuracy, self contained systems are required.

Genisco, Inc.
Los Angeles, California

rate of turn tables — Rate of turn tables are necessary to check the angular accuracy of a gyro under conditions simulating the motion of a missile frame about the axis of the gyro. The angular accuracy and rate of motion of this type of test device must be more accurate than the gyro itself if the test is to be meaningful. Genisco developed a line of this type of equipment for use in testing and calibrating stable platform gyros for missiles, and gyros for autopilots. These units have been widely adopted by airlines for maintenance and calibration of their gyro equipment. Development was funded by the company.

2. Electronic Computer Systems

The contribution of the missile/space effort to the field of computers and automation seems to be primarily in the areas of miniaturization, reliability, input-output techniques and, to a lesser extent, some aspects of computational speed. In addition, various missile/space oriented governmental agencies and companies have provided a market for sophisticated special purpose or scientific computer systems.

Isolating the total missile/space technology transfer to this field is an impossible task for several reasons. First, the field is so broad that to describe it in detail would require volumes. Second, computer applications are so widespread that there have been myriad other stimuli, outside the missile/space program, to the rapid growth of the industry. Finally, although many persons interviewed in connection with this study were certain there had been and would be some positive missile/space contribution, they could name only a few specific contributions close to their own sphere of knowledge when pressed for detail--again due to the broadness of the field.

No attempt then to define the missile/space contribution in detail will be made. Rather, the whole computer discipline will be put in historical perspective, current trends discussed, and an analysis made of the probable contribution of the missile/space effort, based on literature in the field and opinions of persons interviewed in the course of this study.

It appears obvious from a historical analysis that governmental requirements, particularly defense, provided a prime impetus to initial advances in computing equipment. It has been contended that defense requirements financed and directed most computer development.[5] Even so, it would be rather artificial, and perhaps impossible, to say which part of the total defense contribution to computers can be attributed to the missile/space effort.

The electronic computer is a recent development, the first serious thought being given to its construction in the 1940's. Computer history, however, began with a machine built by Pascal in 1642 which would add and subtract. Leibnitz, in 1694, extended the capabilities of this machine to multiplication and division. Charles Babbage, in 1822, designed the first semiautomatic machine which would calculate functions; he called it the "difference engine." Work was never completed, though, because government financing ran out. Babbage, a man of insight, was the first to suggest the use of punched cards (then being used to program woven designs in the Jacquard loom) to feed data to computers. He also predicted that computers eventually would be able to choose between alternatives. Hollerith, in 1889, applied punched cards to the American census in a machine for data sorting.[6]

In 1937, Howard Aiken of Harvard University began work on the design of an "automatic sequence controlled calculator," or Mark I, which was built by IBM, completed in 1944, and donated to Harvard. This machine was significant in that it had a memory that could store numbers. From 1937 on, progress came rapidly. In 1938, Bell Telephone Laboratories pioneered work on computing machines using electromagnetic relays for arithmetic operations. Computing requirements of World War II prompted the development of two large scale computers by Bell Labs under U. S. Army sponsorship. Both were completed in 1946, and both were electromagnetic relay machines. One was located at the Army's Aberdeen Proving Grounds; the other was located at the Laboratories of the National Advisory Committee for Aeronautics at Langley Field, Virginia.[7]

Also under U. S. Army sponsorship, the first electronic digital computer, ENIAC (Electronic Numerical Integrator and Calculator), was completed at the University of Pennsylvania in 1946. Vacuum tube circuits performed all computer operations except input-output. Instructions were set up through a process of switch setting and wire plugging. ENIAC was installed in 1947 at the Ballistic Research Laboratories, Aberdeen, Maryland.[7]

Howard Aiken, designer of the Mark I, produced a similar machine in 1948, Mark II. It was installed at the Dahlgren Proving Ground of the U. S. Navy.[7]

Proposals of J. von Neumann led to the construction of EDVAC, a machine which depended on acoustic delay in mercury for storage. EDVAC, designed in years 1944-1946, was not completed until 1952 at the University of Pennsylvania. Meanwhile, in England, M. V. Wilkes built a machine called EDSAC, patterned after EDVAC. This machine was the first to contain both instructions and numbers in storage (in other words, the first stored program computer). It was used at Cambridge University.[6]

Raytheon completed a machine called RAYDAC in 1953, also based on the EDVAC. RAYDAC was installed at the U. S. Navy's Missile Test Center. Mauchly and Eckert, who had participated in the design of EDVAC, had formed their own company in the meantime; this company was later bought by Sperry Rand, leading to production in 1951 of UNIVAC I. While waiting for completion of UNIVAC and EDVAC, the Air Force contracted with the National Bureau of Standards to produce an "interim" computer. This computer, similar to EDVAC, was much simpler in design. It was completed in 1950 and became the prototype for: FLAC, installed at the Air Force Missile Test Center at Cocoa, Florida; DYSEAC, installed for the Army Signal Corps; and MIDAC, installed for the University of Michigan. All these machines were descended from EDVAC and based on the acoustic delay principle.[7]

Howard Aiken at Harvard completed the Mark III in 1950--the first magnetic drum computer. It was built for the Navy and installed at Dahlgren Proving Grounds. OARAC, similar in design to Mark III, was built by General Electric and installed at Wright-Patterson Air Force Base in 1953. Engineering Research Associates of St. Paul, Minnesota, also developed a line of magnetic drum computers, but these were not related to the Mark III. This company later became a division of Sperry Rand, and its machine became an early model of the UNIVAC Scientific.

Magnetic drum storage is now used exclusively only by smaller computers, although it is sometimes used as auxiliary storage by larger machines. Its advantage is that it is comparatively inexpensive. IBM's 650 and Burroughs' Datatron both have magnetic drum storage.[7]

Both acoustic delay memories and magnetic drum memories suffer from long access time. F. C. Williams at the University of Manchester developed a fast random access memory system using a cathode ray tube, the Williams Tube Memory. J. von Neumann adopted the Williams Tube for the Institute of Advanced Study's computer at Princeton. The University of Illinois built both the ORDVAC, installed at Aberdeen Proving Grounds, and the ILLIAC, which stayed at the University of Illinois, on the Williams Tube principle. MANIAC I at Los Alamos, ORACLE at Oak Ridge, Tennessee, and AVIDAC at Argonne Laboratories, University of Chicago, were also based on the Williams Tube principle. All these systems were completed about the same time, 1952-1953. IBM's 701 and 702 use both Williams Tube and magnetic drum.[7]

M. I. T., storing data on cathode ray tubes, constructed Whirlwind I, completed in 1950. Dissatisfaction with this type memory led the group at M. I. T. to look for a substitute. The search resulted in the invention of magnetic core storage. Magnetic core storage was immediately incorporated into Whirlwind I and was so successful that electrostatic and acoustic delay computers were virtually abandoned. M.I.T. subsequently built a series of core memory computers for the military. IBM discontinued its 701 and 702 and brought out the 704 and 705, both with core memories. Sperry Rand substituted a series of core machines, called UNIVAC II, for its UNIVAC I.[7]

Another advance in the early 1950's worth noting was the development of magnetic tapes, both as storage and input devices.[8] This development decreased input time 50 to 75 times. In 1956, multiple magnetic disc memories were developed, the RAMAC file of IBM being a good example. Disc storage provided random access to 5,000,000 characters of information.[5]

Since the mid-1950's, developments in computers have come so fast that it is beyond the scope of this study to document them; rather, current trends will be identified. Starting about 1955, diodes were used in selected parts of a computer, and by 1957 several small transistorized computers had been built. Today, transistor (solid state) systems are being built almost exclusively. Smaller and more reliable solid state devices are permitting designs that would never have been economically feasible with vacuum tubes.[9]

At the apex of computer systems in 1959 was SAGE, designed for Continental Air Defense. Working with tremendous reliability, this system processes streams of raw radar data, makes computations, and presents visual displays of air space occupation to Air Force personnel.[9] At present, IBM's STRETCH and Sperry Rand's LARC are among the more sophisticated machines. STRETCH has 16,000 words of storage, a one microsecond access time, and a two microsecond addition time. It can read 62,000 characters per second and perform read-write-compute operations simultaneously. It can also interrupt operations to handle problems of higher priority. LARC has a 10,000 word core storage, with a two microsecond access time. It adds in four microseconds and can read at the phenomenal speed of 200,000 numerical characters per second. Both STRETCH and LARC were developed for the Atomic Energy Commission, and both are now available commercially.[9]

Large systems entering the commercial market today are, for the most part, transistorized and use core storage. Great speed, ability to optimize speed by looking ahead a few steps in the program, sophisticated error detection and correction, ability to flexibly modify instructions, simultaneous read-write-compute capabilities, and other assets of STRETCH and LARC are built into these computers. Examples are IBM's 7090 and 7080, Remington Rand's UNIVAC III, Bendix's G-20, Honeywell's 800, and Control Data's 1604.[9] In memory systems, core memories are used for quick random access, and magnetic drums, magnetic tape, and magnetic discs are used for storing bulk data. Being investigated are: 1) thin magnetic films which possess a preferential access of magnetization; 2) cryotrons in which a current in a superconductive material is controlled by a magnetic field induced in an adjacent conductor; and 3) tunnel diodes. All three are potentially useful for memory systems because all can be made in miniature arrays and all have extremely fast switching times.[9]

The bottleneck in computing systems is the relative slowness of input-output equipment. Many of the systems designed today can compute while input or output is taking place. Thus most input-output equipment is off line, so that data on cards can be transferred to magnetic tapes, or data on tape can be printed, without disturbing the main computer. Extremely fast printing equipment has been built in the last few years because of this problem.

Systems have recently been developed for data communications--transmission of data from outlying spots directly to the central computer. For example, RCA has announced a technique developed originally for the Minuteman ICBM which can transmit 50,000 characters per second over a conventional two-wire direct cable circuit.[9]

As mentioned earlier, the main input-output missile/space contributions to computer systems are in miniaturization, reliability, input-output techniques, and read-write-compute speed. There are several reasons for this.

Naturally, the transition from vacuum tube circuits to semiconductor circuits was an important step toward miniaturization. Not only are transistors smaller than tubes, but they lend themselves to printed circuit and modularized assembly. Coming into the picture now, the way transistors did several years ago, is the microelectronic circuit. Microelectronic circuitry is discussed in detail in Section B-2 of this chapter. Microelectronic circuits eliminate ninety percent of the bulk, most of the wiring, and ninety percent of the solder connections of conventional circuits.[10]

Initial use of microelectronic circuitry will be almost entirely on spacecraft and missile computers. However, once the initial cost and developmental barrier is surmounted, it is quite probable that microelectronic circuitry will penetrate the commercial computer field, as was the case with semiconductors. The missile/space effort is forcing the accelerated development of microelectronic circuitry for computers.

Miniaturization has several advantages for computer designers besides space saving per se. First, with miniaturization comes reliability. Because microelectronic circuits eliminate much of the wiring and most soldered connections of conventional circuits, they eliminate much of the unreliability inherent in standard electronic circuitry. As systems grow larger, the need for reliability increases. Second, microelectronic circuitry may eventually cut production costs of electronic circuits. Microelectronic circuitry lends itself to mass production techniques. Fairchild Semiconductor usually adds this footnote to its price reduction announcements for micrologic integrated circuit elements: "Our objective is the price of a single silicon transistor."[10] Finally, miniaturization means faster computers. Although the theoretical travel time of an electromagnetic impulse in a wire is one nanosecond (billionth of a second) per foot, the effective travel time is 1.7 nanoseconds per foot. Decision elements operating in the 2.5 nanosecond range have been proved feasible; thus the length of time it takes an electrical impulse to travel one foot is in the same order of magnitude as the time it takes a switching element to operate. Therefore it is logical to conclude that miniaturization will lend speed to computers.[5]

In summary, miniaturized computer components are a must for missiles or spacecraft and will be pushed for that reason. However, there are advantages other than space saving, and thus the non-space interest. It would be inaccurate to state that miniaturization is a "by-product" of the space effort; however, the state-of-the-art is advancing more rapidly because of missile/space requirements.

Reliability is of prime importance in all systems-oriented computers, e.g., rocket guidance, air defense, manned spacecraft, or process control computers.[9] Many computers can stall on the detection of an error; a systems oriented computer cannot. Reliability on the ground may be achieved through duplication; for example the BINAC, built in 1948, was duplicated throughout, and later systems have been as much as 30 to 35 percent duplicated. But duplication causes a weight problem in rocket guidance or manned spacecraft, and on the ground it is expensive. Advances made in forced reliability with a minimum of redundancy for rocket or spacecraft should, therefore, be of great benefit to process control where reliability is equally important but duplication costly.

Input-output techniques and, to some extent, certain aspects of machine time should also benefit from missile/space technology, especially in the area of process control. For example, a system such as Nike-Zeus must detect an enemy missile, compute its trajectory, and "lock on" with its own missile--thus the need for speed. In addition to speed of computation, however, there must be a way of converting tracking data to a form that can be used by a computer and a way to convert computer output to a form that will position the missile. This is only one example in the missile/space field. There are many other similar situations in guidance and tracking of any missile, rocket, or satellite where data must be converted and reconverted automatically. Such missile systems are quite analogous to industrial process control equipment where physical data (such as temperature) must be converted to a form that can be monitored by the computer.

For example, the California Research Corporation, a subsidiary of Standard Oil of California, has helped develop systems which rapidly scan appreciable amounts of data, convert the data to digital form, process the data in a digital computer, and make automatic adjustments. These systems are used in petroleum or petrochemical refining. California Research buys most of its data acquisition and processing equipment from others, but staff members are of the opinion that the missile/space effort has contributed substantially to the development and availability of this type of equipment. [11]

Of course, in guidance or process control, analog computers can be used to make the computations without conversion of data to digital form. E. L. Harder notes a full order of magnitude in improvement in the accuracy of analog computers in recent years[5] (probably with much impetus from missile guidance). However, for many uses, analog computation is still too inaccurate.

Examples of data processing systems and components which have benefited by the impetus of the missile/space program follow.

North American Aviation, Inc.
Autonetics Division
Downey, California

<u>RECOMP(R) computer series</u>

A recent brochure describing the Autonetics Division of North American Aviation contains the following paragraphs in its introduction:

"With the actuality of space and missile hardware have come unprecedented requirements for precision and reliability. Multi-million-dollar ICBM's and spacecraft are not expendable. Such products must be sure of performing missions precisely and reliably--as nearly every time as it is possible to attain through the most carefully planned and most skillfully executed design, production, and test efforts.

"To assure present day and planned mission success--that can be counted on with the requisite of almost 100 percent reliability--new methods of micro-tolerance manufacture have had to be developed, as well as new techniques for precise prediction of reliability . . .

"Many of Autonetics' activities have been and are directed toward a particular Department of Defense requirement for inertial navigation systems and instruments, computers, data handling systems, armament systems, and flight control systems. However, the great fund of engineering knowledge and manufacturing techniques developed in these areas through the years has made possible similar advances in the industrial products field, and Autonetics now shares a substantial percentage of scientific computer and computer peripheral equipment market. Other specialized products, utilizing the unique skills developed by Autonetics, are now in development and soon will be serving additional industries in defense programs here and abroad . . ."

One of the product lines of the Industrial Electronics Division, Autonetics, is the RECOMP computer series--desk-size, all-transistorized, general purpose digital computers.

The RECOMP series of computers utilizes a transfer of space technology in this sense: computer techniques developed for Department of Defense missile computers were incorporated into the RECOMP series. It is unfortunate that the missile connection cannot be made more specific, but the commercial computer series is not a simple adaption of a military computer; therefore the contribution is primarily a carry-over of know-how. RECOMP computers are used mainly for scientific computation and industrial control. Firms and institutions using the RECOMP include: petroleum firms, electronics manufacturers, producers of optical equipment, scientific reasearch institutions, and many governmental agencies.

<u>automatic</u>
<u>checkout</u>
<u>equipment</u>
(potential)

Autonetics' Computers and Data Systems Division is equipped through participation in the GAM 77 Hound Dog, A3J Vigilante, and Minuteman programs to provide engineering and production assistance on automatic checkout equipment, equipment which checks the missile electronics system before firing.

ACE (Automatic Checkout Equipment for the Atlas missile) and BASE (Basic Automatic Checkout Equipment now in production for the Minuteman) are card or tape programmed computer-like machines which check the missile's electronic circuitry before firing. Through building this equipment, Autonetics has acquired technology that will facilitate the design of automatic checkout equipment for any electronic system. The NIFTE (Neon Indicating Functional Test Equipment) and the NAVAPI (North American Voltage and Phase Indicator) are examples of present technological transfer. The NIFTE will perform high speed continuity checks of wiring in telephone centrals, computers, and other complex electronic equipment. The NAVAPI will test and check out networks, gyros, transformers, and other components with high accuracy.

Autonetics has no commercial application of the NIFTE or NAVAPI as yet, but believes that it will find such application in the future. More important, Autonetics feels that knowledge developed with respect to automatic checkout devices will have widespread future application in testing more complex industrial electronic gear.

Sperry Rand Corporation
Remington Rand Univac Division
New York, N. Y.

Univac, as a supplier of electronic data systems, has supported United States missile/space programs for many years. Initially at Univac commercial computers were used for this activity. Later, government support combined with company investment to materially advance the state-of-the-art in computer technology. As a result, data systems with guaranteed reliability over a broad range of speed and capability are available. In addition, new packaging and component technology permits miniaturized design applicable to virtually all automation and control problems.

Since 1950 and the completion of UNIVAC I, Remington Rand has been involved in research directed toward advanced electronic systems for data processing and control. The transistor was invented in 1948 and transistors became available in limited substantial quantities in 1950-1953. Some studies were made during that period to determine the possibility of using transistors to replace electron tubes in computers. Although it was immediately apparent that the transistor was a capable switching and amplifying device, nearly a decade of engineering development was required after 1948 for the general production of transistorized electronic computers. The principal improvements resulting from this effort were: the reduction in size and power consumption of the transistorized equipment over that using electron tubes, and greatly enhanced reliability as in, for example, the UNIVAC Athena computer for missile guidance. The widespread use of printed circuits with semiconductor devices has made possible a certain degree of automation in computer fabrication. Further development of this technique is destined to play an important role in construction of future machines.

<u>thin magnetic film and Microtronic circuit computers</u> (potential)

One of the most promising research and development programs Univac has pursued is investigation of properties of thin magnetic films and techniques for using arrays of elements comprised of such films. Together with associated printed and electronic circuits, thin magnetic films provide both the function of memory and logic in data processing equipment. A recent development from this program is a thin film memory which meets many of the most stringent environmental requirements for aerospace application.

Recognizing the importance of reliability in spaceborne, as well as commercial, computers, Univac has had a reliability program in effect since 1955. Problem areas which have been researched include: 1) probability of failure, and approaches to the problem of reducing this probability; 2) consequences of failure; 3) means of identifying the cause of failure; and 4) systematic approaches to obtaining timely and effective corrective action.

Historically, a primary purpose of a missile-borne computer is the solution of inertial guidance problems through the processing of data from an inertial system. As missile systems have evolved, other functions have been assigned the essential guidance computer, including engine control, stellar tracking, system checkout and testing, and telemetry serializing. The Univac <u>Aerospace Digital Development</u> (<u>ADD</u>) was designed by Univac to meet the increasing demand on vehicle-borne computational equipment without a corresponding increase in weight. The small integrated package design of ADD is achieved through a combination of magnetic film memories, solid state electronic elements, and welded circuitry.

Univac introduced its Microtronic computer in early 1963, a unit constructed largely of microelectronic semiconductor circuits. One model of Microtronic weighs less than 17 pounds and has a memory of 4,600 words, which can be expanded to 14,000 words if necessary. The development of Microtronic products has been largely a result of the increasing requirements for small, well integrated, high speed, highly reliable computers for use in space vehicles.

Univac feels that magnetic film memories and Microtronic techniques of making microelectronic circuitry may find future application in Univac's commercial computers due to speed, reliability, and the fact that microelectronic circuitry lends itself to mass production techniques.

* * * *

Thin film memories have been in development for about fifteen years. Their first successful application was as a small auxiliary memory in the TX-2 computer of M.I.T.'s Lincoln Laboratory in 1959.[12] Many companies are now developing or producing thin film memories which are currently finding application in aerospace computers. At present thin film memories are approximately ten times more expensive than the conventional magnetic core.[13]

General Precision, Inc.
Tarrytown, New York

computer technology accelerated

The Librascope Division of General Precision's Information Systems Group builds a line of commercial computers and many airborne, missile, and space computers. It has been the company's experience that commercial digital computer technology has been accelerated by the missile/space effort. Missile/space demands on computer design include small size, light weight, high reliability, and low power consumption. Improvements in power consumption, reliability, or size have been and will continue to be factored into commercial design.

For example, partially because of power limitations in space, computers have been designed to operate in terms of milliwatts rather than watts. Cutting the power requirement by a factor of 1,000 means the end of bulky air conditioning systems used by older commercial systems. As another example, reliability in commercial computer systems has been achieved in the past by redundancy. Naturally, redundancy would cause a weight problem with missile/space computers and it makes commercial systems expensive. Newly developed means of achieving reliability without redundancy will therefore have commercial application.

Minneapolis-Honeywell Regulator Company
Aeronautical Division
Minneapolis, Minnesota

self-adaptive autopilot

In the Spring of 1941, a group of Honeywell engineers visited Wright Field with one of the company's first military products, an electronically controlled aircraft camera mount which would keep the camera steadily pointed downward during flight. There they learned of the need for a flight control system similar to the camera mount. The Norden bombsight was not as accurate as desired because pilots, being human, were unable to maintain the exact air speed, altitude, and course heading needed for optimum bombing accuracy. Minneapolis-Honeywell's engineers approached the problem by duplicating a pilot's motions in an electronic device containing gyros, servomotors, and a computing device called an autopilot. Throughout 1942 the device was improved and changed to meet the requirements of the B-17D (the original device had been developed for the B-17B) and in November 1942 the device was successfully tested. The autopilot (called the C-1) was credited by the Air Force with increasing bomber efficiency by 40 percent.

Meanwhile, Honeywell engineers started work on flight controls for the new longer range bombers and the earliest jet fighters. An E-6 autopilot was flight tested in February 1946, and appeared on the B-50's and B-36's of the post-war Strategic Air Force.

Before the E-6 was in production, the company was developing a later model--the E-11--for supersonic aircraft like the F-89, RB-66, Canada's CF-100, and others. Later, the MB-3 autopilot was developed for the first operational plane to fly supersonic speeds in level flight, and other models were developed for the F-101B Air Defense Command All-Weather Interceptor and NATO's Lockheed F-104 Starfighter.

In 1955, Honeywell concluded that the traditional design approach to flight control systems was reaching a point of diminishing returns. Modifications in the basic concept produced only minor improvement. The problem was this: conventional autopilots had to be electronically taught in advance the conditions they would encounter, and they required a constant flow of information from air data sensors on the speed and density of the atmosphere. It became apparent that these limitations eliminated the conventional autopilot from the running for future craft designed to explore manned maneuverable space flight. The conventional autopilot could not be programmed for the many flight variables encountered in hypersonic speeds through the earth's atmosphere into space.

The answer to the problem was found in self-adaptive electronic circuitry, a computer system which adapts automatically to compensate for varying flight conditions such as speed, altitude, weight, and wind gusts. A gyro system is used as the main sensing element.

Six years of research and engineering went into the development of adaptive flight control. Honeywell's first flight test of an adaptive system took place in March 1958 in a fully instrumented F-94-C jet aircraft. These tests proved the feasibility of such a system. The early adaptive work was done both on company funds and under contract to the Air Force's Aeronautical Systems Division, Flight

Control Lab. Out of this early work came more tests in high performance aircraft and, finally, work on adaptive flight control systems for the X-15 and the Air Force's X-20 Dyna-Soar manned space glider.

A direct transfer of technology from the X-15 and X-20 research on adaptive flight control (the company says, "As if a whale had spawned a minnow") is the H-14 adaptive autopilot for light twin-engine aircraft. The advantages of the H-14 autopilot are: simplicity reduces the pilot's task and cuts down the possibility of pilot error; and safety is enhanced by the autopilot's ability to adapt to unforeseen conditions. Several aircraft manufacturers are marketing the new adaptive autopilot as a recommended system for their twin-engine business aircraft.

* * * *

One problem in a systems oriented computer is how to convert analog data into digital input form, which can be used by the computer. Examples of analog-to-digital conversion devices follow.

Genisco, Inc.
Compton, California

analog-to-digital converter — In 1952 Genisco built an analog-to-digital converter for inclusion in a device called an Icono Log, used for converting information from photographic theodolite film to punch card data for computing the flight path of early missiles. The converter was an electromechanical device for taking mechanical displacement (for example, a pair of cross hairs) and converting the position to an electrical signal, digital in nature. Although the original unit has been abandoned for a family of high speed equipment, Genisco now manufactures a second generation analog input-to-digital-output system which embodies somewhat different principles. This is finding wide application in automatic weather stations and processing plants. The development of both original and later devices was funded by the company.

Epsco, Inc.
Cambridge, Massachusetts

analog-to-digital converter — Epsco's analog-to-digital converter is another example of an improvement which can be traced to the rigid design requirements necessary for missle/space equipment. Existing components which were being sold to a commercial market were developed to operate in missile environments; these are now being sold commercially to companies requiring more rugged equipment. This converter features solid state modular construction.

Litton Industries, Inc.
Guidance and Control Systems Division
Woodland Hills, California

shaft-to-digital encoder — Litton builds shaft-to-digital encoders which are used to convert rotating shaft positions to electronic signals. Though this application antedates missile/space programs, these programs have given impetus to small, lighter, more precise encoders. An example of non-missile/space application of Litton's encoders is in their analog computers.

General Precision, Inc.
Tarrytown, New York

contactless shaft-to-digital encoder — The missile/space and aircraft industries have created a demand for a contactless shaft-to-digital encoder which General Precision has built. Contactless encoders operate without mechanical contacts and for this reason last longer and are more reliable.

In the absence of mechanical contacts, the signal must be generated by the encoder optically, capacitatively, or magnetically. Besides the aerospace use, these encoders have found a limited market in the chemical industry where corrosive chemicals shorten the life of all controls, particularly those dependent on mechanical contacts. The newness of the device and its high cost have limited non-aerospace sales to date, but General Precision believes that this device will find a larger commercial market as more are produced and the price diminishes. Development was funded by the company.

North American Aviation, Inc.
Rocketdyne Division
Canoga Park, California

IDIOT (potential) — Rocket engine testing work done at the Rocketdyne Division of North American Aviation has resulted in the Instrumentation Digital On-line Transcriber (IDIOT). IDIOT is a high speed electronic analog-to-digital converter; analog data are converted to digital input data and stored on magnetic tapes (a form that can be used directly by digital computers). The instrument will sample 100 input channels at a rate of 10,000 measurements per second, and can be a tremendous time saver in the analysis of test data.

As yet, no commercial application of IDIOT has been made, but licensing arrangements for IDIOT commercial sales are being negotiated at present. Digitizing of analog data is done frequently in a wide range of engineering and research fields.

Epsco, Inc.
Cambridge, Massachusetts

data collecting system (potential) — Epsco has recently developed a portable data collecting system, based primarily on techniques acquired or perfected through work on various missile programs. The system is contained in two carrying cases, averaging less than 65 pounds each, and is fully shock and vibration mounted.

Epsco feels that its system is an economical, practical solution to the problem of collecting and recording physical data for direct input to a digital computer. The system is an integrated, self-contained device which accepts from 8 to 100 high or low level analog voltages and records them for direct computer input. The company anticipates that the system will find use in measuring and analyzing the efficiency of process control procedures in such fields as petroleum, chemicals, and electrical power generation. The system can assist research groups in the evaluation of complex flow or mixing operations and can be used to monitor such parameters as temperature, viscosity, or weight. In the petroleum industry, anticipated application is the collection of data concerning oil well production.

Gulton Industries, Inc.
C. G. Electronics Division
Albuquerque, New Mexico

<u>process</u>
<u>control</u>
<u>techniques</u>

The application of digital techniques to spaceborne vehicles for information retrieval, guidance, and control introduced Gulton's C. G. Electronics Division to solid state digital control concepts. Equipment supplied by this division is used in several programs, including Sergeant, Apollo, Blue Scout, and the S-17 Solar Observatory satellite. New techniques in digital data acquisition and digital data handling on these programs have been applied by the division to industrial and utility process control in the form of unmanned control stations for natural gas storage and distribution.

The company states that currently most industrial automation techniques still utilize old methods involving pneumatic or electro-mechanical relay equipment. During the next four or five years, the use of solid state digital control techniques in the space program will transfer with significant impact to the area of industrial process control. Costs will be lowered and reliability increased.

Fairchild Camera and Instrument Corporation
Syosset, Long Island, New York

<u>aluminized</u>
<u>data tape</u>

(potential)

Fairchild has built programmers for missile/space vehicle launching which incorporate a new kind of "punched tape." The tape is an aluminized plastic in which optical holes are made, not by physical punching but by evaporation of the aluminum coating. This allows higher density information storage, a principle applicable to commercial computers. Fairchild states that the tape itself is no more expensive than standard paper tape, and cheaper when considered in the light of the amount of information per inch. As yet, it has found no commercial market.

D. POWER SOURCES

1. Solar Cells

The modern solar battery is a semiconductor device for converting radiant energy directly into electrical energy. It contains a P-N junction parallel to and very near the surface of the semiconductor. When radiation of sufficient energy, greater than the band gap, falls on this surface, the radiation is absorbed with the creation of an electron-hole pair. These carriers diffuse from their point of origin and a fair fraction of them, depending upon their lifetime, reach the P-N junction. The minority carriers diffuse across the junction (are "collected"), resulting in a separation of charge and correspondingly a photovoltage. When this device is connected in an electric circuit, a photocurrent results whose magnitude is limited by the intensity of incident light and the impedance of the circuit.

Photovoltaic effect originated with the experiments of Becquerel in 1839, using metal electrodes and an electrolytic solution. As early as 1876, Day and Adams observed a photopotential in the presence of light with a junction between selenium and iron. During the first half of this century much technology was developed in light-measuring devices based on such junctions, silver-selenium and iron-selenium being the favorites. These were not then treated in terms of semiconductor theory, but the photoeffects of rectifying junctions were extensively studied and adequately reproducible. In general, the power output was adequate only to drive a meter and was not considered as a power source.

With the advent of semiconductor devices, including well defined P-N junctions, a change in this pattern gradually developed. In 1941, Ohl described the effect at a P-N junction in silicon.[1] In 1951, researchers at Bell Telephone Laboratories mentioned the collection of photoelectrically liberated charges at P-N junctions.[2] In 1952, Shive of Bell Labs described measurements on such a junction illuminated from the edge.[3] After the development of diffusion techniques for doping semiconductors, others at Bell produced the first silicon solar cells conforming to present design ideas.[4]

At this point it became apparent that substantial amounts of power could be furnished by such a device. The principles and applications were well treated by Cummerow of General Electric and Prince of Bell Labs.[5] By 1955, a rather thorough survey of material and design ideas had been carried out by such workers as Loferski of RCA and Jackson of Texas Instruments.[6] Reynolds of the Air Force's Aeronautical Systems Division, an early worker in the field, generally stressed cadmium sulfide as a cheaper material.[7] In 1960, Wolf of Hoffman Electronics gave an excellent description of the problems.[8]

During the late 1950's, government agencies interested in the missile/space effort began to support R & D on these devices. Electronic News described many of the company efforts and sponsoring groups.[9] It is difficult to assess the true balance of support between space and non-space groups since some groups were interested in both terrestrial and space applications. However, as soon as these devices became reasonably efficient, the major portion of the funding was from space related groups.

Work progressed at a number of locations. ASD continued Reynolds' work on CdS and the Army Signal Research and Development Laboratories undertook studies of N-on-P junctions, under J. Mandelkorn, noting the extensive Russian use of N-on-P systems for satellites. The advantage of N-on-P devices in the presence of high energy protons is now quite well accepted. The use of "idealized" band gap materials was represented by work on cadmium telluride at Armour Research Foundation and on gallium arsenide at RCA. The multiple cell approach, suggested by Jackson, was being studied in dichroic mirror form and multilayer form by Electro-Optical Systems and Texas Instruments. Jackson of Texas Instruments later reported a two element device with overall efficiency as great as 17 percent. The idea of a single cell involving a variable band gap received favorable support and was progressing at Eagle Picher Research Laboratories. The thin film approach to such cells was being investigated, principally at General Electric. Cheaper materials were represented by the work of International Rectifier Corporation on selenium, and of Harshaw Chemical Company on evaporated cadmium sulfide. Work in most of these areas is continuing. Though there are recent reports of space tests on gallium arsenide by RCA, the principal cell in use is still silicon, with Hoffman Electronics the principal producer. The use of polycrystalline silicon is being recommended by certain Russian scientists for economic reasons.

Applications of solar cell space-related developments to non-space areas follow.

Hoffman Electronics Corporation
Industrial Products Division
Los Angeles, California

<u>solar</u>
<u>cell</u>
<u>applications</u>

The economic feasibility of solar-powered products can be directly traced to the space programs, although the technical feasibility cannot. After the first silicon solar cells were produced by Chapin, Fuller, and Pearson at Bell Labs, some were used experimentally to power various demonstrating equipment. In 1954, the Semiconductor Division of Hoffman Electronics Corporation, which at that time was known as National Semiconductor Products, took up the experimental work of Bell Labs and brought the silicon solar cell to the point where it could be manufactured by conventional semiconductor techniques. Commencing in 1955, many efforts were made to find practical applications for the solar cell. In 1956, Hoffman Electronics established a solar cell applications engineering group. This group made many devices utilizing solar cells, including automatic repeater stations, one of which was operated from solar power on top of Santiago Peak in Southern California for the U. S. Forest Service. They also made solar-powered flashing lights for the Coast Guard, to be used as markers on piers, and solar-powered radios, flashlights, and clocks.

The Vanguard I satellite, which was successfully launched in March 1958 was the first artificial earth satellite of any country to utilize solar cells as a source of power for the communications gear aboard. The satellite is still transmitting information whenever the solar cells are illuminated during its orbit. These solar cells were manufactured by Hoffman.

In recent years, Hoffman has sold hundreds of thousands of solar cells to Jet Propulsion Laboratory and other organizations associated with NASA and the space effort.

As a result of the requirements for a great many high efficiency cells to be used in satellites, a considerable quantity of less efficient cells have become available for non-space use. Solar cells are useful wherever a reliable, maintenance free, long life source of electrical power is required--particularly where conventional power sources are not available but the sun shines with reasonable frequency.

Specific products or applications developed by Hoffman Electronics around the solar cell are as follows:

<u>portable radio</u> — This consumer product can now be sold at a reasonable price because of the space program. Hoffman has sold quantities of three models of solar-powered radios to the general public over the last four years. The price of these radios was reduced from $150 to approximately $50 as a result of decreased costs of lower efficiency solar cells which were by-products of the production of high efficiency cells for space satellites.

<u>community listening center</u> — The economic status of people in many nations does not permit them to purchase individual radio receivers. In India and other emerging nations, community listening centers have been established so that a single receiver can serve a whole village. This keeps the population informed and also provides entertainment. In areas where electric power is not available and it is not convenient to supply batteries, the solar cell is used as a source of power.

<u>emergency call system</u> — This system provides emergency services to mortorists stranded on freeways, turnpikes, and superhighways. Since the system uses solar cells, it is self-contained and can be mounted on any post or lamp pole. The stranded motorist simply pushes a button which describes the service needed (e.g., police, ambulance, service truck). The button turns on the transmitter and sends the message. A visual display at the receiver gives the location of the call and shows the type of service needed.

The system has been installed on the central portion of the Los Angeles freeway network, under a contract with California Division of Highways.

<u>telephone system</u> — Solar cells are being used to power a telephone system in South Africa.

2. <u>Thermionic and Thermoelectric Energy Conversion</u>

Thermionic and thermoelectric power generators convert heat energy directly to electrical energy. In this section, only the method of heat conversion will be considered; the particular mode of heat generation--chemical or nuclear--will not be discussed.

<u>Thermionic converters</u> consist of a heated cathode and a cooler anode, or collector, separated by a short space, either evacuated or filled with an ionized vapor at low pressure. Heat applied to the cathode causes some electrons to attain enough energy to escape the surface of the metal. Initially these electrons collect around the cathode, providing a space charge which would prevent the escape of further electrons. The nearby anode, however, collects these energetic electrons, draining off the space charge and allowing continuous current to flow, itself becoming negatively charged with respect to the cathode. The ability of a hot cathode and collector in a vacuum to supply power to an external electric circuit has long been known and was proposed as a normal power source as early as 1915 by Schlichter.[10] However, the phenomenon remained a laboratory curiosity until 1958. Since 1959, much effort has been expended to make practical thermionic converters.[11]

There are two general types of thermionic converters: the vacuum diode and the plasma diode, or plasma thermocouple. The former depends upon a very closely spaced anode, e.g., within 0.0003 inch of the cathode, to reduce the space charge. In the latter, the reduction of space charge and thus of internal impedance of the generator is accomplished by means of an ionized vapor, usually cesium, whose slow moving positive ions collect principally in regions of excess negative charge. With this system, electrode spacings in excess of 0.05 inch are reasonable.

Cesium vapor thermionic converters have been made with conversion efficiencies as great as 15-17 percent. General Electric has recently marketed a vacuum device with an efficiency of about 2.5 percent.[12] By 1961 the more efficient plasma device was subject to pilot plant studies.[13] Solar thermionic converters have had serious attention from both Thompson Ramo Wooldridge and GE.[14] Thermo Electron Engineering Corporation has been active in both the vacuum diode field, growing out of earlier work at MIT, and the plasma diode field.[15] Atomics International has been principally concerned with plasma diodes.[16] General Atomics has worked extensively in the nuclear-thermionic area.[17]

The use of refractory "fuel elements" as cathodes was first discussed at Los Alamos.[18] It has been taken up by several companies, and much work in the field was reported at the Colorado Springs "Symposium on Thermionic Power Conversion" in May 1962. RCA has been working on lower temperature systems, recently under sponsorship of the Navy Bureau of Ships. Other work is sponsored by BuShips (nuclear powered) and NASA. A combined effort of Thermo Electron Engineering Corporation and Minnesota Mining & Manufacturing Company has produced a thermionic-thermoelectric cascade generator.[19] Electro-Optical Systems Company has NASA support in this field. It appears that the missile/space effort has been a source of much of the support for work in this field. The exceedingly high energy density and the high exhaust temperature, allowing radiative exhaust, both contribute to this application.

The thermoelectric converter is, generally, an electric circuit composed of two different conductive materials with the two junctions held at different temperatures. This effect, in thermocouples, has long been used to measure temperature and has even provided enough power to actuate furnace switches. In the modern device for energy conversion, one visualizes a pair of cylindrical legs, one of a P-type and the other of an N-type semiconductor. The hot junction is formed by bridging the two legs with a metallic bar, e.g., copper. The cold junction is the open joint of the circuit where the electrical load is attached, again by metallic bars. The hot junction bar is immersed in the source of heat and the cold junction bars in the cooling medium, often air or water. A voltage, in the open circuit, or a current, in the closed circuit, is generated proportionate to the temperature difference between the junctions. The value depends upon the Seebeck coefficients of the two materials. (See Section B-3, "Thermoelectric Refrigeration," for more detailed information and references.)

Although the phenomenon was observed by Seebeck as early as 1821, it was not useful as a source of power because of the low Seebeck coefficients of the metallic conductors tested. The possibilities of power conversion began to appear in the late 1930's[20] and were greatly expanded by the Russian work under Ioffe. Although thermoelectric properties of materials have been an easy and useful property to measure, particularly among semiconductors, it was not until about 1955 that an intensive search for materials as a basis for a thermoelectric industry began, and then a very large number of people entered the field almost immediately. After Telkes and Ioffe, it is difficult to make any assessment of priority or even of detailed justification.

Government interest in thermoelectric converters has been well monitored by the Navy. The materials search is probably best represented by work at Westinghouse.[21]

The development of lead telluride, the work horse of thermoelectric generators at the present time, was advanced at Minnesota Mining & Manufacturing for use in the SNAP III generator.[22] Their efforts in thermoelectric generation began as early as 1950.

In converters using radioisotopes as the primary power source, such as the SNAP generators, the energy of alpha and/or beta particles (with some contribution from gamma rays) is converted to heat by absorption of these particles in the material of the device. This heat is then converted to electricity by either thermoelectric or thermionic means. Certain of the SNAP generators have employed thermoelectric conversion. (See the Martin Company description following this introduction.)

A fairly extensive program in high temperature materials has been carried out by General Electric. Both General Electric and Westinghouse have been broadly involved in the problems of generator design.[23] Dozens of other companies have been involved in materials research and/or converter development. Two early reviews of the status of the thermoelectric field were published by the Navy and Electronic Industries.[24] It is almost impossible to make a selection among the contributors. Mention should be made, however, of the contribution of RCA to materials development[25] and the production of commercial generators by Texas Instruments[26] and Minnesota Mining & Manufacturing.[27] Although development of thermoelectric generators has had far greater government support than has work on thermoelectric cooling, it is difficult to determine what portion of this came directly from the missile/space effort, although there has definitely been a contribution. Quiet sources of power and relatively efficient and lightweight sources for small scale portable equipment were among the early goals of this endeavor.

Examples of missile/space effort technological transfer in these areas follow.

General Electric Company
New York, New York

thermionic energy converter

(potential)

Current thermionic energy conversion development efforts of the General Electric Company originated with the early work of Dr. Volney C. Wilson, conducted in the General Electric Research Laboratory and wholly company funded. It led to subsequent company advancements in both the vacuum converter and vapor converter areas.

In early 1959, the Cambridge Research Center provided, through the Missile and Space Vehicle Department of GE, government funding for the Research Laboratory and the Power Tube Department to continue the company's efforts in thermionic conversion research and development. Concurrently, the Missile and Space Vehicle Department provided both company and other government contract support for the Research Laboratory, the Power Tube Department, and the Atomic Power Equipment Department in the development of an isotope heat source to which a thermionic converter could be attached. Also, the Missile and Space Vehicle Department undertook development for the U. S. Air Force of a solar thermionic power supply using the first commercially produced vacuum thermionic converters. These converters had been developed by General Electric with company funds.

Currently, both government-sponsored and company-sponsored developments are continuing in the vapor thermionic converter area. The primary foreseeable use of thermionic converters of this type is in space power systems; solar heat collectors and isotope and nuclear reactors are being considered as heat sources for these systems.

Thermionic converters are considered to have possible future commercial applications as topping devices (devices effective for converting waste heat to electricity) for use in central power station operation. Additionally, they are foreseen as possibly applicable in systems which provide electrical power at remote unattended locations, e.g., microwave relay stations, irrigation pumping stations, and weather transmittal and navigational beacon sites. In such applications, the required heat sources can include fossil-fuel-fired means in addition to the mentioned solar heat collectors and isotope and nuclear reactors.

Martin Company
Nuclear Division
Baltimore, Maryland

radio-isotope fueled generator

Late in 1958 the Nuclear Division of the Martin Company began a 15-month research program sponsored by the Atomic Energy Commission. There were three objectives of this program: 1) to find a compound of strontium-90 suitable for use as a heat source in thermoelectric generators; 2) to find materials to contain the selected strontium compound; 3) and to conceptually design a low-power generator to use the heat source. In March 1960, the AEC awarded Martin a contract to design and fabricate a strontium-fueled 5-watt generator. In July, the AEC again contracted with Martin to produce a data telemetry package designed to receive its power from the 5-watt generator.

It is obvious that radioisotope-fueled, direct-conversion generators were first demonstrated in terrestrial applications; however, R & D yielding refinements and improvements to adapt them to space applications has been reflected in the design of terrestrial application units and given impetus to their development. Two SNAP (Systems for Nuclear Auxiliary Power) generators fueled with plutonium-238 are orbiting the earth in the Navy's Transit Navigational satellite. The same fuel will be used in SNAP generators for the operational Transit System. Curium-242 will fuel SNAP generators aboard NASA's Surveyor vehicle. A recent contract calls for a feasibility study for a 500-watt SNAP generator using a thermionic energy conversion system for space applications.

An example of non-space applications of these nuclear generators is in an automatic meteorological data transmitting radio station. This station has been designed and fabricated by the Martin Nuclear Division for the Division of Isotopes Development, U. S. Atomic Energy Commission and the U. S. Weather Bureau, for unattended service at a remote Arctic location. The system, which constituted the first nuclear powered remote automatic weather station, was installed on Axel Heiberg Island in the Arctic on August 17, 1961. It transmits weather information at three-hour intervals to a manned U. S. Weather Bureau Station at Resolute Bay, 200 miles distant.

In addition to the Axel Heiberg weather station, the following generators have been built or planned (under AEC contracts) with strontium-titanate as their fuel: a weather station for the Navy at McMurdo Sound; a Coast Guard buoy; a Coast Guard lighthouse; a Navy floating weather station; and a Navy ocean-bottomed navigational beacon.

Additional uses of isotope power sources are under consideration for other remote weather station application, and as power sources (using cesium) for undersea monitoring devices to detect nuclear blasts.

3. Fuel Cells

No instances of missile/space transfer of fuel cell technology resulting in a commercial product were identified in this study. However, several organizations contacted considered that the potential commercial applications of fuel cells could be classified as possible future transfers from the missile/space program. As is the case in most areas, there has been much pre-space and concurrent non-space research in this field. Because of the widespread interest in fuel cell applications, and to clarify the nature of the space effort contribution, a review of fuel cell technological development is presented here.

The fuel cell is difficult to distinguish in a definitive way from some forms of chemical batteries. It involves, as do all batteries, two "metallic" electrodes (electronically conducting materials) separated by an electrolyte (ionically conducting). A chemical oxidant at one electrode takes up electrons; a reducing agent at the other electrode releases electrons. Thus a chemical reaction takes place which requires the transfer of electrons between the two electrodes through an external circuit. The distinctive features of the fuel cell are that generally the "metallic" electrodes do not enter into the chemical reaction but act only as source or receiver of electrons and that the oxidant and reducing agent are generally fed to the cell from a quasi-infinite external source. Certain carbon electrode cells do not satisfy the former condition; regenerative fuel cells do not satisfy the latter and are, thereby, very similar to storage batteries.

Historically, the work of Davy at the beginning of the 19th Century formed the foundation for fuel cell studies, though a hydrogen-oxygen cell was first investigated by Grove in 1839. Actual attempts to construct modern fuel cells were quite extensive during the last decade of the past century and the first decades of this one; they were aimed principally at coal as the fuel and air as the oxidizer. The difficulties of producing a cell of reasonable life and of regenerating the electrolyte proved too great and interest lagged until the late 1930's when renewed attempts were made with a wide variety of chemical systems. Then, work began on the Bacon cell, a relatively high temperature, high pressure hydrogen-oxygen cell.[28] It was not until the postwar period that interest in fuel cells intensified, along with a generally increasing concern over direct conversion techniques.

Since 1959 several good reviews of the fuel cell situation have been prepared, including the Army reports, an article by DeZubay and Shultz, a book edited by Young, and a chapter by Yeager.[29] This discussion has drawn heavily on Army Report No. 1, DeZubay and Shultz, Yeager, and many others.

Although the fuel cell offers sufficient fuel efficiency (potentially 60 percent to 70 percent energy conversion) to make it competitive for central power, most of the R & D support during the past decade has resulted from interest in smaller uses, prime movers, remote stations, and space power. Much of the research effort is industry sponsored, estimated by Moos at almost 80 percent; government agencies supply the remaining support.[30] A large fraction of the direct industrial support comes from the fuel industry; most of the remainder from engine and motor manufacturers. Most of the basic ideas, including redox and other regenerative cells, were proposed during the early work in this field. New contributions have come in the form of electrodes of better physical design, some exotic fuels, ion-exchange, and some new solid electrolytes. It is not yet certain how important the work on "bacterial" fuel cells and photoregenerative systems may prove.

Fuel cell work is generally classified: 1) on the basis of open versus regenerative cells; 2) on the basis of fuel used. The open hydrogen-oxygen cell is the one best developed at the present time. The high temperature system proposed by Bacon is still being pursued for the National Research and Development (now Energy Conversion, Ltd.) in Great Britain, and is under development at Leesona-Moos Laboratories and Pratt & Whitney in the United States.[31] The work of Leesona-Moos and its predecessor, Patterson-Moos, received early support from the Air Force and the Navy Bureau of Aeronautics.[32] The Pratt & Whitney effort is more recent (1959) and development is now being supported by NASA for the Apollo project.[33] Low temperature hydrox cells are being studied quite extensively. Prominent in the field are Justi at the Technische Hochschule, Braunschweig, Germany, and Union Carbide Consumer Products Company in the United States.[34] Allis-Chalmers, the Electrical Storage Battery Company, and Electro-Optical Systems also have been working on low temperature cells.[35]

This work started about 1957 under industrial sponsorship, with consumer use in mind. The government is now supporting some of this work. A variation on the low temperature cell, using an ion-exchange membrane as the electrolyte, has been extensively developed by General Electric.[36] Inorganic membranes have recently been under study at Armour Research Foundation and at Astropower, Inc., under NASA support.[37] A membrane system based on a hydrogen-bromine reaction is favored by Ionics, Inc.[38] The GE work, starting in 1958, was strongly supported by the Corps of Engineers and the Ordnance Corps, and later by the Signal Corps.[39] The work is now proceeding under NASA sponsorship for the Gemini project.[40]

Hydrocarbon-air and hydrocarbon-oxygen cells have been the intended goal of much of the effort in fuel cells. Only limited success has attended these efforts. High temperature cells, involving molten salts (principally carbonates) as electrolytes, have been produced and tested. In recent times research has been undertaken by: Justi in Germany; the Central Technical Institute (T. N. O.) in Holland; the Institute Francaise du Petrol (I.F.P.) in France; the Sondes Plate Research Laboratories in England; and the Consolidated Coal Co., Curtiss-Wright Corp., and General Electric Research Laboratories in the United States.[41] T. N. O. has received support from the U. S. Army since 1958.[42] Consolidated Coal was supported by the Signal Corps as early as 1954; Curtiss-Wright by the Corps of Engineers much later.[43] Natural gas as a fuel has been studied by the Institute of Gas Technology and has recently been publicized by GE, using a solid state electrolyte.[44] The solid electrolyte is not particularly new.

Oxidation of alcohols rather than hydrocarbons has been proposed to ease the problem of anode catalysis. Research in this area, involving low temperature systems and carbon or metal electrodes, is progressing at Signal Research and Development Laboratories, Professor Justi's Laboratory, Esso Research, and Monsanto Chemical Company.[45] Other open systems involving more exotic fuels, such as magnesium, zinc or sodium, are being developed for special applications by Dow Chemical Company, Aerojet-General Corp., Electric Storage Battery Company, National Carbon Company, M. W. Kellogg Company, and Hoffman Electronics Corp.[46] The work at Aerojet-General received early support (1951) from the Office of Naval Research.[47] The National Carbon work has also been supported by ONR and the Kellogg work by the Bureau of Ships. Some attention has been given to a biochemical cell, using bacteria or enzymes to catalyze certain steps in the process.[48]

Regenerative cells also take many forms. This area of R & D has had a greater amount of support from space oriented groups. Those in which the electroactive reductant and oxidant are regenerated chemically are usually classified as "redox" systems.

Work on such cells has been pursued at General Electric, at King's College, London, and at the Diamond Ordnance Fuze Laboratories.[49] The General Electric work was sponsored by the Corps of Engineers and the Ordnance Corps.[50] Attention has been given to thermal regeneration, accepting the Carnot limitation on efficiency, by the Mine Safety Appliance Research Corp., Tapco Division of Thompson Ramo Wooldridge, Inc., Electro-Optical Systems, Inc., and Allison Division of General Motors.[51] The MSA work began in 1959 under Signal Corps support, as did the EOS work.[52] Photochemical regeneration has been studied by Lockheed under Signal Corps sponsorship and by Sundstrand.[53] Electrolytic regeneration is a more common technique for space applications, where the fuel cell operates simply as a storage system. Most of these systems are based on hydrogen-oxygen, as exemplified by the work of General Electric, Pratt & Whitney, Electro-Optical Systems, Inc., and Ionics, Inc.[54] General Electric and Pratt & Whitney have proceeded under Signal Corps sponsorship. EOS work recently originated under NASA support.

It is apparent that a large amount of work on fuel cells is in progress. It is also apparent that the space program does not dominate the field, but rather follows it. The high fuel efficiencies make fuel cells appear potentially applicable in central power stations. Westinghouse, which has worked in this field for several years, has recently been awarded a $1 million contract from the Office of Coal Research aimed at central power based on pulverized coal.[55] Remote stations are getting a start, e.g., the Stanton, Kentucky station of Columbia Gas, powered by a Pratt & Whitney fuel cell system.[56] Power for prime movers has been demonstrated by Allis-Chalmers, Electric Storage Battery Company, and Chrysler.

These civilian applications dominate much of the thinking in the field. The area of electrolytic chemical production has been seriously explored, including both organic and inorganic chemicals. In the military area, both M. W. Kellogg and General Electric are working on systems big enough to power a small ship or a submarine. Fuel cell back-packs for powering electronic equipment are quite well developed. Power for remote buoys can be reasonably provided.

The principal contribution of the space effort to this field appears to have been in the development of more regenerative systems, and in general financial and moral support of already established R & D programs.

4. Magnetohydrodynamics

Basically, magnetohydrodynamics (MHD) is concerned with interaction between magnetic fields and high temperature ionized gases. For many years, studies in this field were largely limited to those performed by astro-physicists and individuals engaged in studying gas discharges. A summary of the application of magnetohydrodynamics to the study of sunspots, along with a bibliography, has been prepared by Elsasser.[57]

Generating electrical energy through interaction of a conducting medium with a magnetic field is an old idea. Faraday's discovery in 1831, that an electrical voltage could be induced in any conductor by relative movement between the conductor and the magnetic field, is the basis for the conventional generator where a coil of wire (armature) revolves in a magnetic field.

An MHD generator produces an electrical current from an ionized gas flowing through a magnetic field. An ionized particle moving through a magnetic field will be deflected in one direction if it carries a negative charge and in the opposite direction if it carries a positive charge. By superimposing a magnetic field on an ionized, high speed fluid--such as that produced by a rocket engine--and placing collectors in an appropriate position to intercept the positive or negative charges, an electrical voltage between the collectors can be produced.

Due to advantages resulting were electricity to be produced without moving parts, several patents dating back at least 50 years were granted which dealt with the production of electric current as the result of the motion of a conducting fluid relative to a magnetic field. An inadequate understanding of the phenomenon involved prevented exploitation of these ideas. Probably the most thoroughly tested of these was the Karlovitz-Halasz generator developed at Westinghouse Electric Corporation between 1933 and 1946 which apparently suffered from insufficient conductivity of the gaseous medium.[58]

The gas to be used in a magnetohydrodynamic power generator must conduct an electric current and therefore must be partially ionized. While the temperatures required are high, they are not greatly different from those encountered in rocket engines and hypersonic flow. However, gases could not be heated readily to sufficiently high temperature to become good conductors of electricity until the shock tube had been developed as a tool for hypersonic research.[59] The electrical properties of shock heated gases were then studied, and the experimental results verified theories on electrical properties of gases.[60] The process by which the gas approaches an equilibrium ionization value after being heated by a shock was also studied.[61] It was found that the temperatures required to produce a conducting gas could be reduced if an easily ionizable impurity was added to the gas.[62]

The ICBM re-entry problem which became important in the 1950's, and later problems in space propulsion, accelerated and supported studies of high temperature properties of gases and the interaction of these conducting gases with electrical and magnetic fields. The application of the magnetohydrodynamic forces to exert drag on and reduce heat transfer to a re-entry body was considered. As part of an investigation of electrode operation in a high velocity hypersonic gas flow, a magnetohydrodynamic generator using argon developed, for a short time, more power than was consumed by the field coils.[63]

During this period, theoretical and experimental work on one-dimensional flow in a closed channel such as would be utilized in a magnetohydrodynamic generator was also studied.[64] The construction of an experimental magnetohydrodynamic generator was started in 1958 to obtain both an observable amount of power and information on phenomena related to magnetohydrodynamic generator operation.[65] Other work included a theoretical analysis of the problem and experimental work by the British with a shock ionized argon generator.[66]

In November 1959, Avco-Everett Research Laboratory and the American Electric Power Services Corporation initiated a joint study to investigate the possibility of MHD power generation and the problems involved.[67] (See the Avco-Everett description following this introduction.) The studies included both nuclear and conventional power sources such as coal. Both open and closed cycles were considered.

Although Avco-Everett has received or provided the most public attention in the field of MHD generation, several other companies also have been active in this field, particularly since 1959. Westinghouse has developed reasonably successful power generators based on internal combustion and seeding with alkali metal compounds.[68] The company is pursuing a closed loop study for the Air Force Aeronautical Systems Division under contract AF33(657)-8311. Westinghouse also has been giving considerable attention to non-equilibrium ionization, reported by E. J. Sternglass at the Third Symposium on the Engineering Aspects of MHD at Rochester, March 1962. In 1960, Thompson Ramo Wooldridge built and tested a small MHD generator for space applications. The company is testing the idea of a vortex flow system under NASA support. General Electric has been working on MHD systems under Air Force support for several years, and recently, for the Office of Naval Research.[69] GE has also been concerned with non-equilibrium ionization under ASD support, contract AF33(657)-8298.[70] A new method for heating the electrons above the gas temperature, proposed by Sutton, Hurwitz, and Tamor has looked particularly interesting. Martin-Marietta has recently been doing work under Office of Naval Research sponsorship.[71]

It is to be noted that although the gas must be ionized, thermally or otherwise, it is the kinetic energy of the flowing gas stream which is converted to electrical energy. This kinetic energy results from expansion of the heated gas through an appropriate nozzle and sets the expected Carnot limitation on efficiency. It is not easy to reduce the equivalent exhaust temperature of the jet to a low figure, so that the energy efficiency of the MHD generator by itself is likely to be on the order of 30 percent to 40 percent at best. Use of the exhaust heat to drive a high temperature turbine, or a thermionic converter and other low temperature converter in thermal series, makes it appear that an overall energy efficiency of 60 percent to 70 percent may be achievable.

Avco Corporation
Avco-Everett Research Laboratory
Everett, Massachusetts

MHD generator (potential)

The study of missile re-entry problems has developed a good theoretical understanding of the electrical conductivity characteristics of gases at high temperatures in ranges above those normally encountered in thermal power plants. This new understanding raises the possibility of technically feasible and economically attractive plants for the large scale generation of electric energy using magnetohydrodynamic principles.

Avco-Everett Research Laboratory conducted studies of missile re-entry and high temperature gas dynamics, beginning in 1955, under contract with the Air Force Ballistic Systems Division. Studies of magnetohydrodynamics were also carried on under contract with the Air Force Office of Scientific Research.

In November 1959, Avco-Everett Research Laboratory and the American Electric Power Services Corporation initiated a joint study to investigate the possibility of MHD power generation and the problems involved. While it is not yet certain that a magnetohydrodynamics central station power plant can be built, there appears to be a good possibility that this development will take place, possibly within the next ten years.

The principal advantage of such a plant would be the much higher thermal efficiencies. It is estimated these would approach 60 percent as compared with the present 40 percent maximum.

While the commercial power plant program is sponsored by Avco Corporation and the electrical utilities, other aspects of MHD power generation are being investigated under Air Force Ballistic Systems Division contract. The Air Force Office of Scientific Research is also sponsoring basic studies of MHD phenomena at Avco-Everett.

E. PROPULSION

1. Cryogenics

Although the field of cryogenics (the science of very low temperatures) seems relatively new to the layman, its history extends back to 1862 when Joule and Thompson demonstrated that a gas could be cooled by expansion through a porous plug. Approximately thirty years later von Linde and Claude each invented a machine for liquefaction of air, using this basic principle. These machines, and their later modifications, became the basic tool for liquefaction of gases. The demand for cryogenic fluids increased greatly during World War II and has continued to grow. Today the most widely used cryogenic fluids are oxygen, nitrogen, helium, hydrogen, fluorine, and methane.

Oxygen has been the most commonly used cryogen, its consumption increasing steadily since the Linde Company set up the United States' first air liquefaction plant in 1907. It was not until the 1930's, however, that trucking and handling oxygen in liquid form became common practice, significantly reducing the overall shipping cost per cubic foot of gas. This made it economically practical for the steel and chemical industries to adopt wider usage of oxygen. Production of liquid oxygen is now an important facet of U. S. industry. The steel and chemical industries are the largest consumers of liquid oxygen with the rocket and missile industry ranking third. Liquid oxygen is the oxidizer most commonly used in liquid-fueled rocket engines. It was used in the early Rocketdyne engine for the Redstone missile and in the engine of the Viking missile. It is currently being used in both the Atlas and Titan I missiles. It will probably remain in this dominant position for rocket use for quite some time, due to its advantages of relatively low cost, resulting from its distillation of liquid air, and its relative ease of handling.

Liquid flourine is the best oxidizer currently available but it has the drawback of being extremely toxic and corrosive. At present, it is not employed because of these deterrent effects. However, because it can increase the performance of a propulsion system by as much as 40 percent, much work is being done to increase its applicability. [1]

Liquid hydrogen as a rocket fuel appears destined to increase in usage because of its high specific impulse. Specific impulse is the total impulse of thrust provided by the combustion of a unit mass of propellant. It is proportional to the combustion temperature of the fuel and inversely proportional to its molecular weight. [2] Since hydrogen has the lowest molecular weight, it has a correspondingly high specific impulse. It is currently being used in the Centaur and Saturn space vehicles, under development by NASA.

During the period 1860 to 1946 many other advances were being made in the field of cryogenics, culminating in the development of a commercial helium liquefier by S. C. Collins of MIT in 1946. This made available in commercial quantities the coldest (-452°F) of the cryogens. Liquid helium is being used in research at temperatures close to absolute zero. Much of this research is indirectly connected to the space program, as explained below in connection with superconductor research.

Another cryogenic fluid used in missile/space activities is nitrogen, although this field represents only a modest part of nitrogen's current market. Its uses in the missile/space program include: space simulation in which it acts as a "shroud" surrounding the simulation chamber to keep it cold; as a pressurizing medium to transfer rocket propellants; to test parts that will be in contact with liquid oxygen; as a purge for missile components; to quick-cool wind tunnels; and as an inert atmosphere for shock-absorption of hydraulic landing gear. [3]

It is clear that a theoretical background in cryogenics was quite fully developed when missile/space requirements for cryogens began to be felt. In addition, some of the cryogens, especially liquid oxygen, had been in practical use for some time. However, there were some unique requirements imposed by missile and launch site specifications which led to new developments and/or improved techniques in cryogenics. The result was to make available more equipment, instrumentation, and techniques that are used in a variety of commercial applications.

It was necessary, for example, to improve on the design of storage vessels (dewars) for these cryogenic fluids. Better insulation techniques were developed so that vaporization losses could be significantly reduced. Improved or new designs in cryogenic instrumentation were required, e. g. , liquid level measurement, flowmeters, etc. Very exacting requirements for cryogenic system cleanliness were imposed since small foreign particles could seriously impair rocket engine performance or cause explosions, resulting in expensive delays.

Transportation and storage of cryogenics is another important consideration in the missile/space industry. Since a missile or rocket conceivably could stand on its launch pad for years, it would be impractical to store liquid oxygen in its tanks, due to vaporization losses and freezing of control valves. Therefore, tons of propellant must be loaded for launch with the utmost speed. The major problems involved in this process are line cool-down and heat transfer to the fluid. The solution of these problems lies in the selection of suitable design, materials, and insulation techniques. The technological advances which were made as a result of these requirements are being adapted to commercial practices.

There are other important applications of cryogenics where the missile/space effort has made an indirect contribution deserving of some comment. The most significant of these is the phenomenon called superconductivity. This characteristic of some metals was first discovered by Onnes, a Dutch physicist, in 1911. Experimenting with the effects of liquid helium, he found that mercury had no resistance to flow of electricity at temperatures below about -455°F. This was the first of a series of discoveries about the strange behavior of materials near absolute zero temperatures which have precipitated a large amount of scientific research in the last few years.

Superconductivity has significant implications in both commercial and missile/space fields, hence a transfer of superconductivity technology from one to the other. The areas in which superconductivity may be utilized in the missile/space programs include:

1. It can be used to make extremely fast switches, called cryotrons, for use in digital computers. Dissimilar metals, usually lead and tin, are used. A small current flowing in one of the superconducting lead strips will create a magnetic field which will destroy the superconductivity in any tin strip it crosses. Therefore, by turning on a small current in the proper lead strip, electrical currents in selected tin strips can be switched off. The advantage of the switch is its high speed--it operates in nanoseconds. Computers capable of such speeds could be used by missile defense systems where an enemy missile has to be identified and its trajectory plotted.

2. Extremely powerful magnetic fields can be constructed using superconducting wires as the field source. For example, cryogenic gyroscopes, or cryogyros, are being developed in which a light spinning sphere of metal is suspended in a magnetic field, thus virtually eliminating friction. These may find use in inertial guidance systems of missiles and space vehicles.[4]

3. Another application of the large and strong magnetic fields which can be generated using superconductivity is magnetohydrodynamic (MHD) space power. While MHD is only theoretically feasible at the present time, its use is predicted for ion propulsion systems, space stations, or auxiliary power systems where one megawatt of power or more is needed. It is reasonable to predict that this will generate much research on the application of superconductivity.

Examples of transfer of missile/space technology in this area follow.

Air Products and Chemicals, Inc.
Allentown, Pennsylvania

broader use of cryogenic liquids due to missile/space needs

Air Products and Chemicals, Inc. produces and commercially distributes cryogenic liquids. Missile/space requirements for large quantities of cryogenic liquids have resulted in expanded facilities throughout the industry and contributed to significant price reductions.

The reduction in price for some of these cryogenic fluids has been sufficient to permit their use in additional commercial applications. For example, Air Products and Chemicals is now supplying cryogenic fluids for truck refrigeration systems and private research.

The development of most of the equipment required for the production of cryogenic fluids was funded by the company. Some government support was obtained for the development of hydrogen and helium liquefaction equipment.

Tennessee Products and Chemical Corporation
A Subsidiary of Merritt-Chapman & Scott Corporation
Nashville, Tennessee

improved cryogenic insulation

Expanded perlites have been used for a number of years as light weight aggregates in concrete and plaster, and as industrial filter aids. The missile/space need for suitable insulating material for tanks of liquefied gases brought about the development of this special insulation grade of expanded perlite.

In missile/space programs this material serves as insulation in ground support equipment storage tanks, primarily for the storage of liquid oxygen and liquid hydrogen. This improved insulating material is also used in the fabrication of tanks and equipment for industrial handling of cryogenic fluids by such firms as Air Products and Chemicals, Inc. and Chicago Bridge and Iron Company.

The development leading to the improved product was funded by the company, working in conjunction with customer firms.

Stearns-Roger Manufacturing Company
Denver, Colorado

dewars

(potential)

Dewars are generally considered to be double walled vessels with intermediate insulation capable of storing liquefied gas at -150°F or colder. Sir James Dewar

(1842 - 1923) is usually given credit for the development of this type of vessel, but prior to the aerospace age dewars were small and expensive laboratory type equipment. Missile/space requirements made necessary the development of large units for storing vast quantities of liquefied gases. Stearns-Roger designs, manufactures, and tests dewars for these uses. The company anticipates several commercial applications for these large units. It is currently conducting studies for customers in the natural gas industry to determine feasibility of using these vessels for shipment of liquefied methane and other hydrocarbon fuels. Other uses for these dewars, of which the company is aware, include bulk storage of liquid oxygen for improvement of steel production, storage of liquid nitrogen for use as a refrigerant to freeze perishables, and storage of liquefied gases for medical use.

Graver Tank & Manufacturing Company
Chicago, Illinois

<u>improved tank cleaning techniques</u>

Any tank for the storage of liquid oxygen must be cleaned with extreme care because of the danger of explosion, should any trace of organic matter or other readily oxidizable substance remain. Tanks for the storage of cryogenic fluids, because of the nature of their use, usually require careful cleaning to preclude contamination. Also, any traces of water or other liquid or vapor that can freeze at cryogenic temperatures must be eliminated to prevent plugged openings and other troubles.

Rigid specifications and the large number of vessels involved in cryogenic liquid handling for missile base installations required improvements in cryogenic tank cleaning procedures. Graver Tank & Manufacturing Company developed, with company funds, a chemical cleaning technique to meet the cleanliness and particle size requirement for vessels to be used for the storage of liquid oxygen, nitrogen, and other cryogenic fluids.

Similar techniques are now used in cleaning cryogenic vessels for commercial use.

Martin Company
Denver Division
Denver, Colorado

<u>liquid hydrogen technology</u>

(potential)

The Denver Division of the Martin Company has a variety of research focused on liquid hydrogen: how to measure its level, stratification, temperature, and flow; how it affects materials' properties; how to pump, insulate, and store it; and how it reacts to nuclear heating, and to zero gravity environment. The use and promise of liquid hydrogen as a rocket and space vehicle propellant is the only current reason for this program. Although there are no present commercial uses, liquid hydrogen is being considered for application in the computer field. This application would call for the immersion of entire matrices in cryogenic fluid to secure superconductivity. Liquid hydrogen technology would be the foundation of such a development.

Various aspects of the program have been funded by the company and several government agencies.

* * * *

Although liquid helium is generally thought of as the cryogen for use with cryotrons in computers, liquid hydrogen could also be used with some alloys. It is much cheaper than liquid helium and has a higher specific heat. (The same quantity of liquid hydrogen will absorb more heat than liquid helium with less change in temperature.) Its main disadvantage is its combustibility.

2. Fluid Transfer Systems

From the time that the earliest systems were devised to use a fluid as a working medium, problems concerning control of fluid flow have arisen. As solutions to these problems were evolved, broader and more efficient use of fluid power resulted. To cite an example, James Watt is credited with improvements for the first steam engine (1769). His main initial contribution was the separation of the condenser from the steam cylinder, the beginning of a system. As this power generation system was developed to provide better performance, and as the turbine entered the picture, a closed system for control of the working fluid was evolved. This system encompassed many mechanical devices including pumps, auxiliary turbines, piping, valves, and seals. These devices controlled the flow of the fluid, in both gas and liquid states, to and from the major system components, e.g., the boiler, main turbine, etc. Improvements in design and efficiency of these auxiliaries to the steam engine kept pace with advancements in other technological areas with mutual benefit being derived.

Today one or more of a wide variety of fluid transfer system components can be found in almost any mechanical device which uses fluid as a lubricant or as a working medium. These components have been adapted to the requirements of all types of industrial applications involving fluid transfer equipment. Many of the applications are highly specialized, such as in the cryogenic industry discussed in the previous section.

With the development of rocket powered missiles leading to space flight, engineers were challenged with a great number of new system problems. A variety of liquids were to be used which posed difficult handling problems. They could be extremely cold, noxious, highly reactive, intractable, or self-igniting. Not even a small amount of such a fluid could be allowed to leak from the system. The environment in which some of these components were required to function with high reliability also included high and low extremes of temperature and pressure. In general, the components used in the solutions to these problems were basically like their counterparts in earlier systems, but with special emphasis placed on reliability and weight reduction.

A typical example, which illustrates the complexity of problems mentioned above, is that of the turbine-pump combination required to supply oxidizer and fuel to the rocket engine. A system which has been used on many missiles involves a turbine which drives both the fuel and oxidizer through a gear box. The high speed turbine is supplied with high pressure gas, from a combustion chamber, which may have a temperature of 1800°F. The gear box adjacent to the turbine must have its own supply and circulation system for lubrication of gears and bearings. The oxidizer pump adjacent to the gear box may be pumping liquid oxygen at -297°F. Two of the problem areas are immediately apparent: that of preventing leakage of the incompatible fluids along high speed shafts, and that of coping with the high thermal gradient across the gear box. These and other problems are linked with specific components and discussed in more detail below.

Pumps

A wide variety of problems, requiring special development in pump design, were encountered by missile systems engineers. For the purposes of this discussion, however, the example cited above adequately illustrates the implications of space requirements.

Centrifugal pumps were primarily used for pumping liquid oxygen to the rocket engine. Cryogenic fluids had been previously handled by such pumps but not with such high volumes and pressures as required by the rocket engine. A primary problem was that of cavitation at the pump inlet. Cavitation occurs when the static pressure at some point in the system drops below the vapor pressure of the fluid being pumped. Some of the fluid flashes to vapor forming an instable gas bubble which then collapses when it moves into a higher pressure area. When this happens, the pump discharge pressure fluctuates, which can lead to oscillations strong enough to destroy the rocket chamber.[5]

To overcome this problem, it was necessary to carefully control all design parameters affecting net positive suction head and to improve manufacturing processes and eliminate surface roughness in the pump inlet and impeller. The addition of an inducer to raise pump inlet pressure slightly was used in some cases.

Examples of pumps developed for the missile industry are described below, together with the nature of technological transfer to non-missile/space applications.

Sundstrand Corporation
Sundstrand Aviation Division
Denver, Colorado

centrifugal pump

The Office of Naval Research sponsored an analytical research investigation on low specific speed pumps and turbines, performed by Sundstrand Aviation. The objective of this investigation was to determine which of many types of turbines and pumps would provide optimum performance in various operating conditions applicable to missile/space auxiliary power systems. The optimization technique developed, using specific speed and specific diameter as parameters, proved to be powerful and revealing.

By applying this technique of analysis to known problem areas in other fields, Sundstrand has found commercial application for a high speed, single stage centrifugal pump which had previously been used in missile applications. This uncomplicated, reliable pump design has been successfully placed in operation on commercial jet aircraft and in an oil field application under the trade name Sundyne. The potential for broader future use of this pump appears to be excellent.

Pyles Industries, Inc.
A Subsidiary of Kent-Moore Organization, Inc.
Detroit, Michigan

fluid transfer equipment

Pyles Industries has developed machines and related accessory equipment to pump, meter, mix, and dispense single and multiple component fluid materials, primarily in the production of plastic products. Originally, the company manufactured hydraulic pumps for automotive grease, oil, sealers, and paints. The growth of aircraft and missile/space industries linked the need for these basic pumps to more sophisticated application equipment for handling multi-component materials.

Although the basic concept of a ball valve is old, the widespread development and use of ball valves by industry is recent. Ball valves are similar to plug valves except that they offer full round flow and do not require lubrication.

Hills-McCanna developed a special ball valve for use in missile launchings which had to pass severe mechanical and hydraulic shock tests. Shortly after the successful completion of these tests, the company learned that a major builder of tank cars was interested in a bottom unloading tank car valve. This type of valve would have to pass similar tests because a mechanical failure could be costly and dangerous. With a modification of the missile valve, the company was able to offer a satisfactory tank car valve. Thus the development went from a commercial product, to a valve for a specific missile application, and back to a commercial valve offering a substantial future potential in areas where a standard commercial valve would not be acceptable. Industries using these valves commercially include petroleum, petrochemical, chemical, pulp and paper, and allied process industries.

North American Aviation, Inc.
Rocketdyne Division
Canoga Park, California

<u>soft seated valves</u>

Rocket propulsion activities engaged in by Rocketdyne require valves that can perform difficult tasks. They must be able to handle large amounts of liquid oxygen while being soft-seated at low temperatures.

A valve already in existence was re-engineered by North American and seated with such materials as Teflon, Mylar, and Kel-F. The engineering information was passed back to the company that manufactured the original valve. This company in turn began producing these valves and marketing them to the cryogenics industry.

This valve development took place in conjunction with the construction of test apparatus for the Navaho program in the late 1940's and was funded by the Air Force.

Anderson, Greenwood and Company
Houston, Texas

<u>safety relief valve</u>

The stringent requirements of the Bomarc launching system necessitates a high performance safety relief valve. Anderson, Greenwood and Company, which designed and developed the prototype equipment, developed a new valve with company funds to meet this requirement. It was a soft-seated, high pressure valve which became a standard in the missile industry.

This valve, with later improvements, is incorporated in safety systems where fluid such as liquid oxygen, helium, hydrogen, and nitrogen is used.

The demand of the missile/space programs provided a sufficiently large market for this high quality valve to enable the company to produce it at a commercially acceptable price.

Many of the company's present products were developed to meet a particular requirement of the aircraft and missile/space industries in producing, assembling, or finishing its products. Applications include: handling polysulphide sealant materials; aiding space electronics suppliers in automating potting and encapsulation production; spraying epoxy coatings; and for application of polyesters, ablation materials, urethane foams and insulations.

Commercial uses of this equipment include: the application of polysulphides in automotive windshield sealing and assembly of truck trailer skins; bonding industrial products such as radio speaker magnets; potting electric motors; spraying and flowing polyether and polyester foams; and making FRP boats and other structures. All developments have been funded by the company.

North American Aviation, Inc.
Rocketdyne Division
Canoga Park, California

pump inducer (potential) — As a result of the need for a pump which would deliver large amounts of fuel to a rocket engine, an ordinary centrifugal pump was redesigned by North American Aviation. A pump inducer was added to the pump. This is a screw type mechanism which starts the flow of fluid before it actually reaches the pump. According to the company, this development raises the over-all efficiency of a centrifugal pump and may be extensively adopted for pump applications in many industries.

Valves

The requirements of missile systems made necessary the development of valves which were basically like those used in commercial applications but which had unique characteristics. Very rigid requirements for reliability and high performance were imposed and components usually had to be made smaller with a corresponding reduction in weight. One example is a valve used in the liquid oxygen (LOX) supply line to the LOX pump in a missile system. This valve must remain tightly shut while the LOX tank is being filled. The thermal shock imposed when the valve at ambient temperature is suddenly filled with fluid at -297°F posed a major problem to valve designers. Unequal contraction of hard valve surfaces led to leakage. Soft seat materials were adopted to combat this problem. The valve must also be quick opening and allow very high flow rates with very low pressure drop across the valve. Finally, these valves are remotely operated and must function with a high degree of reliability despite ice which collects on external surfaces of a cryogenic valve.

Other types of valves requiring redesign to meet the rigid requirements of missile/space systems include pressure control and relief valves, hydraulic servo valves, and flow control valves for both high and low temperature extremes. Many of these improved valve designs are finding application in commercial systems, as illustrated below.

Hills-McCanna Company
Carpentersville, Illinois

ball valves — Hills-McCanna Company has adapted for commercial application a ball valve which was developed for use in missile launchings.

Commercial applications are similar to missile/space uses--control of pressure in a variety of systems: polyethlene plants, compressor stations, chemical and petrochemical facilities, and pipeline and transmission systems.

Kieley and Mueller, Inc.
Middletown, New York

improved control valves and regulators — Kieley and Mueller has improved an existing valve to meet missile/space requirements. The improvements give higher capacities per valve, lower weight per valve, faster speeds of operation, and tighter shut-off than was previously available. The development, funded by the company, was motivated by requirements for improved equipment to load liquid fuels and oxidizers into launch vehicles.

The improved valves are beginning to find commercial applications; for example, they have been sold to a commercial company which manufactures oxygen for an acetylene process. In addition, Kieley and Mueller is making efforts to market these valves for low temperature helium separation processes.

Hoke, Inc.
Cresskill, New Jersey

improved stainless steel valves — Hoke produces stainless steel valves for liquid metal service. These valves were originally developed for nuclear applications. The revival of activity in alkali liquid metal research by the missile/space program has necessitated improvements in these valves for use in research on nuclear engines for space vehicles.

Present non-space application of these valves is in nuclear power stations. They are also used in research involving high temperature fluids. These developments were funded by the company.

Seals

No basically new approaches were made on the problem of making missile fluid systems pressure tight but innovations, material changes, and design improvements were made necessary by the new requirements of missile systems. The major problems encountered resulted from the extremes in temperature, pressure, and vibrational environment in which seals must function reliably. Generally the static seals, as used to seal flanges, embody either the "O" ring principle or are self-loading; in both cases an increase in fluid pressure causes an increase in tightness of the seal. This also applies to dynamic seals, such as those used on a piston rod, but the design of this type seal is quite different. Mechanical seals, such as the face type dynamic seal used on high speed rotating shafts are pressure balanced so that the unit load on the face is nearly constant over the fluid pressure range for which it is designed to operate. The secondary seal in such a mechanical sealing arrangement is usually an elastomeric material, but a welded metal bellows has been devised which provides for a more positive secondary seal. Elastomeric materials usually used for "O" ring type applications are the fluoroelastomers (Teflon, Kel-F) because of 1) the wide temperature range over which they can work efficiently, 2) their chemical inertness, and 3) their excellent wear properties.

Some of the seals which were developed for the missile/space industry are now finding commercial applications, as described below.

Harrison Manufacturing Company
Burbank, California

Harold E. Webb Company
Technical Representatives
Burbank, California

metallic static seal — A special metal seal was developed, with company funds, by Harrison Manufacturing Company for use in fittings which were giving considerable difficulty in sealing under the extremes of temperature and pressure experienced in the Atlas missile. The seal is all metal, with metal coatings particularly resistant to radioactivity, and is applicable in installations where exotic fuels or gases are mandatory. In addition, it is resistant to cure dates resulting from the use of elastomers.

Commercial use of these seals is in high and low temperature applications in industry, such as deep well oil drilling, liquefaction of gases, and atomic energy installations. To date, the non-space sales volume has been limited. The company feels there are also potential uses in the pharmaceutical, chemical, and food processing industries.

North American Aviation, Inc.
Los Angeles, California

cryogenic pump seals — To meet the requirements involved in delivering liquid oxygen to rocket engines, North American Aviation helped develop an improved pump seal. These improved seals will operate at cryogenic temperatures and are compatible with liquid oxygen. Increased use is expected throughout the cryogenic industry, including many non-missile/space applications.

Navan Products, Inc.
Subsidiary of North American Aviation, Inc.
El Segundo, California

Natorq metal seals — In the process of solving a test equipment problem in its own laboratories, the Autonetics Division of North American Aviation developed a metal seal which is leak-proof through wide ranges of temperature and pressure (-360°F to 1,200°F; 0 to 10,000 psi). The problem which prompted this development was the necessity of a liquid rocket plumbing system to handle fluids which vary greatly in temperature and pressure.

The seal deforms with torque to become an integral part of the fitting; the seal and fitting can be repeatedly reassembled. Natorq seals have been used on many of the nation's missile, airplane, and rocket engine systems. They may be used in any hydraulic, pneumatic, gaseous and liquid nitrogen, oxygen, and helium system.

This seal is now marketed by Navan Products, Inc.

3. Miscellaneous

FMC Corporation
New York, New York

high strength hydrogen peroxide

Prior to World War II, hydrogen peroxide was only available in concentrations up to 50 percent strength (half peroxide, half water). During the war, a need developed for more concentrated solutions, first as a fuel for chemical submarines and later as a monopropellant or oxidizer for liquid rockets. The successful development of the atomic submarine resulted in a slackening of interest in high strength peroxide for this use, but rocket applications continue.

Hot gases from the catalytic decomposition of high strength peroxide were used to drive the fuel pump in the Redstone missile which served as the first stage of the vehicle which launched the first U. S. satellite. The fuel pump, APU (Auxiliary Power Unit) system, and reaction control jets on the X-15 are all powered by high strength peroxide. Similarly, the reaction control jets on the Mercury capsule and other maneuverable satellites utilize peroxide as a monopropellant. Concentrated H_2O_2 has also been proposed as a source of energy, breathing oxygen and water for space flight applications.

H_2O_2 is a useful material for the introduction of active oxygen into numerous commercial chemical compounds and appreciable quantities of H_2O_2 are used for this purpose. For some of these reactions, high strength peroxide is preferable or even mandatory. Therefore, the present availability of 90 percent H_2O_2 (made possible largely by missile/space requirements) has had a salutory effect on the growth of numerous oxygen-containing chemicals. The industries presently using high strength hydrogen peroxide for chemical manufacturing include those interested in epoxidation and hydroxylation reactions. The more important epoxidation products made in this way are plasticizers and stabilizers for vinyl resins (epoxidized soy bean oil being the prime product) and insecticides (Dieldrin and Endrin).

The initial process work leading to 90 percent H_2O_2 was funded by FMC. Applications work was funded primarily by the Department of Defense plus some NASA funding on the Mercury program.

California Institute of Technology
Jet Propulsion Laboratories
Pasadena, California

wire wound filters

In 1950-1951, Jet Propulsion Laboratories had an Army contract to investigate ways of constructing a porous, yet rigid, material to be used as part of a rocket motor wall. Porosity was needed because the rocket fuel was to be forced through the wall on its way toward ignition, thereby serving the dual purpose of coolant and propellant.

A by-product of this effort was the development of a "wire wound filter." This filter is made from a helical winding of wire which is cylindrical in shape--much like a ball of string. The total configuration is heated to fuse the points at which the windings come into contact, and the end result is a cylinder of porous metal. These are now being used commercially and by the government to filter oil, gasoline, and other fuels. The Bendix Corporation is one producer of wire wound filters.

F. FABRICATION

1. Filament Winding

Filament winding is the manufacturing process by which reinforced plastic structures are produced by winding a resin-impregnated fiber material around a mandrel of the desired shape and then heating the assembly until the resin is cured. The fiber material is generally glass and the resin is usually of the epoxy type. Two types of winding are used, helical and biaxial. Helical windings use a varying pattern to optimize strength in either the hoop or longitudinal direction, while biaxial winding is essentially circumferential or longitudinal with variations to accommodate specific loads.

By the use of a combination of oriented filaments, the maximum advantage can be taken of the strength of the fiber material. Earlier fiberglass reinforced types of plastics were composed of woven cloth in which the kinking of the fiber during weaving introduced a shear stress which lowered the load-carrying capacity of the composite structure.

The theory of single filament winding was evolved about 1947 and testing was started.[1] However, the process was not successful until the advent of improved epoxy resins. Filament winding was used for 3000 psi pressure bottles for jet aircraft starters in 1951.[2] Walter Kidde and Company developed a small air pressure bottle capable of holding 650 cubic inches of air under a pressure of 3000 psi to replace metal storage spheres used as actuators for aircraft hydraulic systems.[1] Aerojet developed pressure bottles for the Air Force's Aerobee high altitude research rocket to contain nitrous oxide at a pressure of 3,000 psi, the first recorded use of a filament wound structure in the rocket industry.[3] Subsequent rocket chambers were made by filament winding for several rockets, including Polaris and Minuteman.

The main advantages of a filament wound structure are its strength-to-weight ratio and its non-conducting and corrosion resistance characteristics.

Today, filament wound rocket motor chambers are being used in the Polaris and Minuteman systems. According to P. L. Layton of the Owens-Corning Fiberglass Corporation, the production of rocket motor chambers for Polaris and Minuteman will be done exclusively by the filament winding method by 1964.[4]

After the initial work by the aerospace industry demonstrated the advantages of this type of structure, civilian applications have been forthcoming, as are illustrated by the following items identified during this study:

Lamtex Industries, Inc.
Farmingdale, New York

Hystran(R) filament wound reinforced plastic

Although the filament winding principle has been known for several years, the missile/space effort has led to considerable refinement in technique. An example is Hystran, a filament wound reinforced plastic produced by Lamtex Industries, Inc. of Farmingdale, Long Island. Recognizing the applicability of filament wound containers to rocket containers and pressure vessels for rockets, Lamtex developed advanced filament winding techniques. Most of the development was funded by Lamtex.

Some of the major missile/space projects now using Hystran include: Minuteman, Mercury, Polaris, Pershing, Scout, Bomarc, Ranger, Nike-Zeus, Vortac, Discoverer, Bolt, Law, and a variety of NASA projects.

Biggest in commercial potential is the turning of Lamtex capability to such product areas as air tanks for truck brake systems, automotive parts, truck and railroad tank cars, and chemical tanks. While none of these has been produced, negotiations are underway. Experience gained in making large rocket chambers enables Lamtex to produce an 8,000-gallon railroad tank car weighing 5 tons less than a conventional steel car.

A current by-product of Lamtex capability is a filament wound brassiere support. The supports are used by many manufacturers to replace conventional metal supports.

In addition, Lamtex has developed filament wound pipe and tubing and hopes to apply Hystran for auto and boat bodies, construction materials, and "hot sticks" for handling high voltage lines.

Black, Sivalls & Bryson, Inc.
Ardmore, Oklahoma

<u>filament winding</u>

In 1957, Black, Sivalls & Bryson, Inc. obtained a license from Young Development Company to do filament winding to make oil field tanks used in the storage of corrosive chemicals. Large (12' in diameter by 20' high) 17,000-gallon tanks were developed with the idea of producing a low cost, corrosion resistant tank for the oil industry. However, in 1957-58, when the oil industry suffered a slump, the company decided to build tanks for other users such as the food industry, wine industry, and chemical industry.

Meanwhile, the company had had inquiries from the Air Force and Navy and in 1958 did research on filament wound rocket motor chambers. As a result of this work, Black, Sivalls & Bryson is now fabricating the motor chamber (the chamber containing the solid fuel) for the second stage of the Polaris missile and for the third stage of the Minuteman missile.

Although the company's commercial product line is in no way a direct result of the missile/space program, the company states that the program has had one significant effect on its commercial line: as a result of Polaris and Minuteman work, the company is able to draw on a much broader base of glass filament and resin technology.

The company's product line includes a family of 17,000, 12,000, 8,600, 4,600, and 1,800-gallon vertical tanks and a family of 1,100, 560, and 300-gallon horizontal tanks, and underground storage tanks. These tanks are sold to firms storing hydrochloric acid, phosphoric acid, corn syrup, wine, alum solutions and animal feed.

The tanks are produced by passing the glass filament through a resin and catalyst bath over a mandrel and oven-curing the tank at 375°F for three hours. This results in a high integrity, high strength-to-weight ratio, corrosion resistant structure.

2. Chemical Milling

Chemical milling is a process used to uniformly remove metal, at a controlled rate, to change the dimension or shape of metal parts. The first step in a chemical milling operation is the application of masking material (usually a neoprene) to cover the part to be milled. Next, those portions of the surface to be milled are scribed and stripped. The third step is immersion in a vigorously agitated basic or acidic bath where the milling process takes place. Finally, the part is removed from the bath, the chemical neutralized, and the mask removed. When more complex shapes are desired, the part may be remasked and remilled several times.[5]

Why is this process different from the old art of engraving which dates back to the 16th Century in the halftone photoengraving process? The main difference is that the objective of chemical milling is to remove a large amount of metal over fairly large surface areas, while etching is a process of removing very small amounts of metal, a little at a time.[6]

Chemical milling was the solution of a relatively small problem at the guided missile plant of North American Aviation in Downey, California. To make a rocket casing, a cylinder made of thin aluminum sheet had to be butt welded, but the weld failed repeatedly because of the thinness of the contact edge. Planing a thick sheet to leave a lip at the edge to be welded would be expensive; using a thicker sheet would have created an unacceptably high weight.[6]

Manuel Sanz, Chief of the North American research group, solved the problem by suggesting that the cylinder be made of relatively heavy gage aluminum and placed in a corrosive bath, covering the edges with some form of masking to protect the edge to be welded. The idea proved feasible; this first use of "chemical milling," as Sanz called it, occurred in August 1953. North American applied for a patent on the process which was granted in 1956.[6]

North American Aviation has made Turco Products, Inc. of Wilmington, California, its prime licensee for the process. Turco has made improvements in all phases of the process as originally developed and holds many patents on these improvements. (See the Navan Products description following this introduction for more detail.)

Advantages of the process include: 1) elimination of weight unnecessary to structural strength, after an intricate part has been formed; 2) ability to mill after heat treatment without affecting the heat treatment condition, and avoidance of warpage which could occur if parts are heat treated after milling; 3) attainment of tolerances as close as ±.002 inch; 4) production of inexpensive contour or tapered shapes through controlling the rate and way in which parts are immersed in the chemical; 5) uniform reduction in thickness of sheet metal, leaving strengthening ribs if necessary; 6) production of complicated shapes eliminating the necessity for welding or riveting various parts together; 7) relatively small investment in equipment; and 8) ability to machine many alloys difficult to machine by conventional methods.[7]

However, there are several disadvantages to the process. Where the work can be machined by ordinary methods, chemical milling may not be able to compete on a cost basis. The scribing operation does not lend itself to automation. Grain-size internal stress and contours which may trap gas bubbles all affect the rate of milling in localized areas. Internal corners are not squared but rounded, and previously locked-in internal stress may be released, causing the part to warp.[7]

Aluminum, magnesium, titanium, tooled steels, stainless steels, monel, Iconel, and various superalloys have been milled chemically with success. Molybdenum, tungsten, beryllium, and tantalum have been milled but experience is lacking. [5]

Examples of transfer follow.

Navan Products, Inc.
Subsidiary of North American Aviation, Inc.
El Segundo, California

Chem-Mill — Chem-Mill is the trade name for chemical milling. Chem-Mill offers commercial industry many advantages. Complex designs can be produced; the conventional procedure--cutting the material into parts, machining and refabricating--is eliminated. Design changes are relatively easy to make, and Chem-Mill is an economical way to mass produce a part where design change is the rule rather than the exception.

The chemical milling process, developed in 1953, solved the problem of thinning an aluminum sheet for a rocket casing, but leaving the edge of the sheet thick enough for a butt weld. Because the method helps solve several problems common to the aerospace industry (production of complex, light weight shapes, frequent design changes without expensive retooling, and maintenance of high standards of accuracy), it received much impetus for further development. As a North American invention, it has been licensed through Navan Products, Inc. to Turco Products, Inc. of Wilmington, California, as prime licensee, and through Turco to about 80 manufacturers and processors.

Because the Chem-Mill process met requirements of the aerospace industry (many complex missile skins and members would never have been produced without the Chem-Mill process) applications by licensees have been most evident in this industry. However, the automotive industry is currently investigating applications of the process. Significant developments have been made on automation of the process, a prime requisite for commercial use.

Turco Products, Inc.
Wilmington, California

Chem-Mill — Turco Products, Inc. of Wilmington, California, has produced many advances in the basic chemical milling process since North American Aviation made it the prime licensee in 1953. These improvements have taken place in all areas of the process--chemicals, maskants equipment, and techniques. Turco now holds 24 patents while North American holds nine.

In turn, Turco has licensed the process to every major American aircraft manufacturer and to many small job-shop companies. Some of these are: Chemical Milling International Corporation, Chemical Contour, Strazza Industries, Chemtronics, Inc., Altamil Corporation, and Anadite Corporation.

Outside the missile/space field, the Chem-Mill process has been used on almost every American airframe produced in recent years. Examples include the Boeing 707 and 720, the Douglas DC-8, and the Convair 880 and 990.

Outside the aerospace industry, the application of Chem-Mill has been limited. At one time it was used to make trunk lids for automobiles but the process was discontinued. It has been used to make parts for certain types of office equipment. Turco hopes to develop more non-aerospace business in the future. The company feels that two important factors have held back its non-aerospace use to date. First, the aerospace business has pre-empted most of the capacity of Turco and its licensees. Second, a considerable amount of time and money must be spent in marketing the process to industries unfamiliar with chemical milling.

3. High Energy Forming

Today's demands in metalworking for more precision, more intricately shaped parts, and large sizes are causing new developments in some unusual metalworking techniques known as high energy forming. Most of these demands, and hence developments, are in the aerospace industry. All techniques have the same basic characteristic in that they utilize high rates of energy to form metals. The various sources of energy are: explosive charges, combustible gas mixtures, and high voltage capacitor banks.[8] Explosive forming is the oldest of these techniques and currently the most common type of high energy forming.

Explosive Forming. In this technique the sheet of metal to be formed is placed over a female die. The cavity between the sheet of metal and the die is evacuated and the die and piece of metal are placed in a tank of water. An explosive charge, shaped in accordance with the job to be done, is placed in the water a calculated distance above the metal sheet. When the explosive is detonated, the metal is rammed into the die. A small amount of explosive will produce forces far in excess of the largest hydraulic press. Those knowledgeable in the field are in agreement that this process has certain advantages for some metalworking operations. Deep drawing, flanging, and sizing operations can be performed at a lower cost with explosive techniques than with conventional processes and equipment.[9]

Much of the research that has been done in this field has been sponsored by the United States government. One report states, however, that most of the government-funded research has been for the application of this process to the fabrication of specific missile and aircraft parts and not for basic research.[10]

The process of using a large, controlled burst of energy such as explosive forming for metalworking began in the late 19th Century. At that time, several patents were issued on a process using shaped explosive charges to emboss and form metals. Early uses of the process included the fabricating of ornate doorknobs and brass spittoons. The process was little used, however, until six or seven years ago when aerospace companies began exploring its possibilities as a method of shaping hard-to-form metals.

Since that time the aerospace industry has led in the development of this process. There has been a great deal of interest in its use for the fabrication of titanium and zirconium alloys, the refractory metals, and other metals having properties suitable for missiles and advanced aircraft.[11]

The advantages of explosive forming over conventional metal forming methods include:

a. The method is particularly suitable for parts needed in small quantities because of low die and equipment costs. Only one die is necessary as compared to two for most processes. In addition, materials such as plaster, wood, or concrete can be used for dies in some instances. Soft alloys, epoxy resins, or low-carbon steel may be used when greater quantities of parts are required. Tool-steels would probably be used for more severe uses. [12]

b. Tolerances in the order of ±.002 inches are easily obtained because springback is minimized. [13] Close tolerances down to ±.001 inches can be obtained if a longer forming cycle and better dies are used. [14]

c. Many large shapes and unusual forms are beyond the capabilities of conventional tools whereas explosive forming is particularly applicable to these needs.

d. There is an excellent uniformity of the parts produced.

e. It has characteristics which aid in everyday engineering productibility such as: the ability to form re-entrant corners, to shape metal in a vacuum or in place in a subassembly, to true up already fabricated structures, and to add cut-outs or stiffening beads to them. [8]

The disadvantage of explosive forming is the associated noise and hazard problem.

Polaris missile heads and missile fuselage sections have been fabricated by this technique. It is also being used to expand symmetrical cylinders and cones of complex, unusual profiles.

The opportunities for using explosive forming in non-missile/space applications should become more apparent as the result of advances made by the aerospace industry. Industries for which uses are readily visualized include the automobile field in the production of truck and automobile bodies in limited quantities, and the chemical and petroleum industries for forming tanks, heads, towers, and similar pieces of equipment involving large shapes of high-strength materials. [15] This is not to imply, however, that this process is likely to replace forming operations that are easily done with current methods and machinery.

Combustible Gas Mixtures. Similar to the explosive forming technique, this method appears more adaptable when the part to be formed is thin and rupture is likely if the pressure is distributed unevenly. The metal is formed by igniting a gaseous mixture in a closed die, usually hydrazine and oxygen. If the gas mixture can be ignited in a uniform manner it produces a change of optimum shape because the energy source assumes the shape of the container. This technique is also used as a supplement to explosive forming when the quantity to be produced is high enough to make open-tank explosive forming uneconomical. This technique was developed at the Boeing Company. [8]

High Voltage Capacitor Banks. Other high energy forming techniques which are based on the conversion of electrical energy into mechanical energy include electrohydraulic and electromagnetic processes. In the electrohydraulic method, a massive electrical discharge from a bank of capacitors sends a shock wave through water to form the metal against a die. The electromagnetic technique builds up a high repulsive magnetic field in the work piece to collapse it to shape in a die. [16]

Electrohydraulic equipment for fabricating titanium, columbium, stainless steels, tungsten, beryllium and their alloys has been developed by the General Electric Company at Schenectady, New York. [17]

The first electromagnetic metalforming machine for industrial use is reportedly in production at the General Atomic Division of the General Dynamics Corporation.

Both of these techniques show promise of being more adaptable to indoor assembly line production than explosive forming.

The following examples are somewhat typical of work being done by firms in the aerospace industry and illustrate the contribution of missile/space activity to the technology of high energy forming. One description shows that some commercial application is already taking place. It is the general consensus that more commercial applications will occur as the methods are perfected and industrial managers become aware of their advantages for particular operations.

North American Aviation, Inc.
El Segundo, California

explosive forming

Although studied by the Los Angeles Division a number of years ago, development and refinement of the method were undertaken by North American's Rocketdyne Division. North American is now setting up a new (separate) facility to do high energy forming. It is a manufacturing process which may have a large potential for commercial application.

Rocketdyne started using the process in 1956 in connection with tube-end forming and later started forming larger sections such as tank-ends.

North American Aviation is doing high energy forming for some customers outside the missile/space industry. One job in particular is for the Braun Citrus Company, consisting of a stainless steel feed wheel for orange juice squeezing requiring very close tolerances and fabricated from a high yield point material. Another is for Watervliet Arsenal in connection with gun bore evacuators and cladding tubing.

Non-missile/space industries most likely to use high energy forming in the future are those engaged in sheet metal forming, tank-end forming, tube forming, hole punching, automotive manufacture, and marine vessel fabrication.

Martin Company
Denver Division
Denver, Colorado

explosive forming

(potential)

Martin-Denver's interest in this known technique was prompted by the fact that it showed promise for the production of certain large metal forms for missiles. The division's primary goal in this effort is the forming of 120" diameter ellipsoidal tank domes for missiles from one-piece, weld-free, flat aluminum blanks.

Martin-Denver's contributions to the technique of explosive forming include:

1. Development of scaling laws of explosive forming has allowed the results of small scale experimentation to be applied to the production of large, full-scale parts. This reduces the high cost of the earlier trial and error method of establishing inter-relationships between shell

diameter, shell depth, and explosive charge, and the formability limits of various kinds of stock.

2. A "plug cushion" method has been developed and a patent disclosure filed by the company. The so-called "plug" is a sheet of soft lead placed over the work to be formed. The plug distributes the shock wave of the explosion more evenly and controls the mass movement of the metal helping it to stretch evenly. The process shows promise of increasing the formability limit by a factor of five, and raises the possibility of free-forming many shapes and dispensing with the female die.

3. Surface treatment techniques have been developed that impart better ductility to the metal being formed.

4. A new technique for forming honeycomb structures explosively is showing very good promise.

It is anticipated that the process of explosive forming can be used commercially in forming a variety of metal shapes, both large and small, and in the areas of welding and heat treating of metals. It should prove economical, particularly for very large metal shapes.

Martin-Denver's work in this area has been company funded.

The Marquardt Corporation
Manufacturing Division
Ogden, Utah

<u>explosive forming</u>

(potential)

In 1957, Marquardt became interested in the explosive metalworking process as a possible means of reducing fabrication time and cost in the production of ramjet engines for the Bomarc missile. Initial R & D was conducted at Hill AFB (Ogden) with cooperation of the Ogden Air Materiel Command and the 25th Ammunition Division. The program resulted in the successful production application of explosive forming techniques to six structural components of the ramjet engine. In 1959, Marquardt built its own explosive forming facility.

A wide variety of explosive working operations are either in current use at Marquardt or being studied for possible future applications. In general, the most advanced operations are those which approximate conventional metalworking, while those in the least advanced stage of development are the ones most dissimilar to conventional methods and which frequently involve very different concepts of metal behavior.

Explosive operations used in current production include forming, sizing, and flanging of sheet metal stock or plate. Other operations in varying degrees of usage or advancement are controlled work hardening, welding, extruding, and controlled cutting and perforating.

Where explosive metalforming techniques have been applied, considerable economies have been realized through simplification of tooling and elimination of hydraulic presses, spinning machines, or other related expensive equipment. It has proven especially advantageous where a limited number of parts are desired and tool and equipment amortization represent a large portion of the production cost.

Facilities for explosive working of metal parts ranging from hand-size objects to large pieces requiring dies up to 10 feet in diameter are available at Marquardt's production facility on a job-lot contract basis, and plans for developing larger facilities are underway.[18]

Marquardt reports that practically all of its current work is for use in missile/space programs. Some experimental work is being done for commercial uses: for example, the production of large water valves for the University of Utah. The company believes most commercial applications of this technique will involve the forming of large tanks and similar items.

4. Solid State Bonding

The terms "solid state bonding" and "diffusion bonding" are synonymous. The process is used for metal-to-metal bonds. Clean, closely fitting surfaces are brought together under the application of pressure with or without the application of heat. In this process the parts can be visualized as "growing" together, the atoms or molecules of one part diffusing into the atoms or molecules of the other. The proximity of the parts on a molecular level, and the resulting inter-molecular attraction, form the bond. No melting is involved.

The cleanliness of the surfaces is an extremely important factor. Soft metals can be bonded in air but only by drastically deforming to attenuate the oxide film. Protection of the surfaces from atmospheric contamination by the use of an ultrahigh vacuum permits bond formation with very little plastic deformation. Some deformation is necessary to insure full contact. Extremely smooth surfaces are not necessary if one of the pieces is soft and is slightly deformed. However, two hard surfaces will bond only if extremely smooth and either flat or of exactly the same contour. If the parts involved do not lend themselves to diffusion bonding, an intermediate metal layer may be employed to effect a better bond.

Diffusion bonding cannot be considered really new since all forms of welding involve a diffusion process. However, welding techniques typically bring the interface to a molten condition and diffusion takes place. The fact that materials placed in good contact would diffuse into one another has been known for many years, but this process has not been used on a practical basis until very recently.

In 1957, Storchheim described the use of hot pressure bonding in the cladding of a wide variety of metals.[19] Evans, in a prepared memorandum on diffusion bonding in 1960, summarized the developments of the technique to date. He stated that applications of diffusion bonding processes in fields other than nuclear engineering were limited, but that interest was spreading. In particular, savings in complex and expensive "missile age" materials through diffusion bonding techniques were a possibility.[20] More recently, Feduska and Horigan of the Materials Laboratories, Westinghouse Electric Corporation discussed a practical method for the diffusion bonding of high temperature alloys using beryllium intermediate strips.[21]

The original impetus for diffusion bonding seems to have come from the nuclear reactor field, primarily as a result of its ability to save expensive material in the process of cladding fuel elements. However, solid state bonding has received much impetus from the missile/space industry because: the process must be understood to keep materials from sticking together in space; it provides a good way to join electronic components; it will join metals to non-metals; the joint structure has properties approaching that of the material itself; and the bond is exceptionally clean.

Examples follow.

National Research Corporation
Cambridge, Massachusetts

solid state bonding (potential) — National Research Corporation, under a contract with NASA's Goddard Research Center, has been investigating the mechanism of solid state bonding and methods to prevent metals from bonding to one another in space. At room temperature in a vacuum, pieces of mild steel stuck to each other so tightly as to require forces one-fifth as great to break the joint as to break the steel itself. At 300°C, joints had one-third the strength of the steel and at 500°C were up to 96 percent perfect. Copper stuck to itself with 60 percent of its natural strength at room temperature.

Solid state bonding involves forcing two extremely clean metal surfaces together in an ultrahigh vacuum until they diffuse into each other forming a single, homogeneous metal. The ultrahigh vacuum prevents contamination and thus permits the surfaces to lock on contact.

This process suggests vastly improved means of joining metal parts such as electronic components. Unlike soldering or brazing, the solid state bonding can yield a blending of two separate parts with the desirable physical and electrical characteristics of the bulk metal. This could be an important development for both the aerospace and electronic component industries. Any practical application of this process, however, will require a great deal more work in ultrahigh vacuum and bonding techniques.

North American Aviation, Inc.
Los Angeles Division
Los Angeles, California

diffusion bonding — The Los Angeles Division of North American Aviation became interested in diffusion bonding because of its work on honeycomb brazing for the B-70 in 1961. Work was pursued through a company funded research program because of its possible advantages to many aspects of the aerospace programs. The Los Angeles Division currently has a contract with ASD to do research on solid state bonding and its application to hypersonic vehicles--both aircraft and winged re-entry.

Advantages of diffusion bonding include: 1) The bond is strong and homogeneous. 2) Metals, such as refractory alloys which are brittle when welded, can be joined with this process. 3) Original properties of the material are not lost in the process and the bond becomes an integral part of the piece.

The process has been used by North American's Atomics International Division to clad fuel elements for nuclear reactors. Potential uses in other areas are being evaluated; for example, North American expects to see it used to make lightweight structures for future hypervelocity vehicles.

5. Miscellaneous

Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

clean rooms

The clean room is used to provide a sterile environment in which to manufacture products that must be protected from contamination. Prior to the missile/space program, Westinghouse utilized clean rooms in its atomic energy programs. In the last five years, however, the missile/space program has placed considerable emphasis on miniaturization. One result has been the improvement and greater use of the clean room in manufacturing this miniaturized equipment. Contamination, temperature, and humidity levels which could be tolerated previously were no longer acceptable. The clean room is now being used to eliminate contamination to the sub-micron size, and also to control the temperature and humidity more exactly.

Present commercial applications of clean rooms include uses in the pharmaceutical, optical, and photographic magnetic tape industries. Since other industries are beginning to utilize miniaturized components, it is probable that the use of clean rooms will become more important commercially in the future.

The results of a recent Westinghouse survey indicate that the number of clean rooms in use will increase four to five times in the next three years. Most of this immediate increase will be due to the missile/space programs.

* * * *

This is an example of an item which was developed and used prior to the missile/space program, improved because of missile/space requirements and subsequently has found broader commercial application because of more widespread knowledge of savings resulting from its use. In other words, the missile/space contribution to clean room technology has been improvement and dissemination.

The Boeing Company
Associated Products Division
Seattle, Washington

fluidized bed furnace

This heat treating furnace is similar to a molten salt furnace, but uses a "fluidized bed" rather than salt. The bed is a volume of granular particles through which air or other gas is circulated. The resulting active air-and-particle mixture behaves much like a fluid. The gas is usually introduced through the porous bottom of the furnace. Items to be treated are suspended in the fluidized bed and quickly reach the bed temperature. The air-particle mixture transfers heat from the source to the item more quickly than does gas. Temperature control and range are more flexible than with salt baths. The violent, random movement of the particles provides a uniform temperature throughout the bed.

Several advantages are offered by this furnace over conventional heat treating furnaces. It provides rapid heat transfer and thus more accurate temperature control, cutting manufacturing costs. It reduces the amount of carbide phase formation and helps ease other metallurgical difficulties. The inert particles which form the bed also eliminate other problems encountered with salt baths, such as deterioration of the salt, danger of decomposition and explosion, loss of salt which clings to the treated part when it is withdrawn, size limitations, and the corrosion and cleaning of the treated material.

The furnace can be operated from -100° to about 3,000°F with the same fluidized material. Temperature can be maintained within ± 5°F at a temperature of 2,000°F or more with uniform (±2°F) heat distribution throughout.

Development of this furnace was necessitated by a problem Boeing encountered on one of its missile programs. Similar furnaces were available, and had been for some time, but they were found to be inadequate to solve this particular problem. Several of these fluidized bed furnaces are now in successful commercial operation in such applications as the heat treating of small investment castings.

Associated Testing Laboratories
Wayne, New Jersey

<u>temperature chamber</u>

As a result of greatly increased reliability demands initiated by the missile/space program, Associated Testing Laboratories has found that many companies require more extensive test facilities than were previously necessary. This has made feasible the development of a relatively low priced temperature chamber, based on the company's seven years of experience in the environmental testing field.

Developed originally for testing rocket and missile components, the device is now used in both continuous production line sampling and in the laboratory. The electronics industry is the primary user. The device occupies a little over a cubic foot of space and has an internal test chamber which is 11" × 12" × 5". Its temperature range is from 350°F to -100°F with a control capability of ±2°F. Heating is through a 115 volt resistance element and cooling is by liquid carbon dioxide (CO_2).

Associated Testing Laboratories states that no comparable units were available at the time their unit (the Mark II Econ-O-Line Chamber) was introduced in March 1961.

* * * *

This is an example of a device, developed to fill an indirect space demand, which later found commercial application. It embodied evolutionary technology rather than major new discoveries.

G. MATERIALS

1. Refractory Metals

Although no present and few specific potential commercial uses of missile/space developments in the field of refractory metals were identified in the course of this study, many persons interviewed suggested that the refractory metals field would be quite lucrative. This section is presented, then, to show the relationship of the refractory metals field to the missile/space effort, and to give background on an area which has frequently been cited in general terms as possessing great non-missile/space potential.

A shift in emphasis from gas turbine technology to missile/space technology has caused a corresponding shift in emphasis in the nation's high temperature materials research and development. The temperatures, ranging from 2000°F to above 5000°F, under which components of hypersonic aircraft, propulsion systems, and re-entry vehicles must operate has meant that work on the conventional nickel, cobalt, and iron based superalloys has decelerated. Work on ultrahigh temperature structural and insulating materials has been greatly intensified. The refractory metals, because of their high melting points and retention of strength at high temperatures, form an important part of this materials research.[1]

Refractory metals are defined as those which melt above 3400°F. There are 12 such metals: molybdenum, tungsten, columbium, tantalum, chromium, vanadium, rhenium, ruthenium, rhodium, osmium, iridium, and hafnium. Of these, molybdenum, tungsten, columbium, and tantalum are of principal interest because of their higher melting temperatures.[2]

Refractory metals in the 1940's were, for the most part, laboratory curiosities. Tungsten of course was used in light bulbs; small amounts of the refractories were used for alloying purposes. Refractory metals were first used in the aerospace industry in 1954 in air-breathing jet engines as a result of the need for operating at higher temperatures to obtain better performance and speed. The first major structural application was in forged turbine buckets for turbo-jet engines and the first major application of sheet metal molybdenum was in a combustion chamber for a ram-jet engine.[3]

In the early 1950's, an important high temperature materials problem was finding structural materials for Mach III vehicles, the F-103, the Navaho, and the B-70. Although not considered a refractory metal, titanium appeared to be the most promising and was developed aggressively. Another problem was re-entry cooling of nosecones, but this was solved using copper-heat sink techniques, ablative cooling, or a combination of metal and ceramics.[4]

Although much progress has been made to date, many problems exist in the refractory metals field. The materials are generally brittle, hard to fabricate, and difficult to weld. The most serious problem is oxidation. At high temperatures, the refractories are subject to rapid oxidation, meaning that unless the materials can operate in a vacuum or reducing environment--or oxidation-resistant alloys can be discovered--protective coatings are imperative.

Provided the oxidation problem can be solved, the use of refractory metals in the aerospace industry may be divided into five categories. High Mach number aircraft--up to Mach 10--represent a large potential use of refractory metals. The structural material involved must possess adequate strength at operating temperatures of 2000° to 2500°F.

In operational space vehicle applications, it would be economically advantageous to use recoverable boosters. Not only must the structural material withstand re-entry temperatures approaching 2000°F, but the structure must have sufficient tensile strength to contain a high pressure fuel.[5]

Ballistic and semi-ballistic re-entry problems have been solved, as has been discussed, but winged re-entry vehicles such as Dyna-Soar (X-20) must be able to withstand a heating range of relatively low magnitude and long duration. This implies radiation cooling at temperatures of 3000° to 3800°F, which in turn implies the use of refractory metals.[5]

Designers of liquid fueled rocket engines are able to combat the heat problems by using the fuel itself as a coolant, but temperatures are generated in solid fueled rockets which require use of refractory metals. Nozzles and control devices of solid fuel rockets now use refractory metals extensively.[6]

In the space vehicle itself, refractory metals will be used in components of thermionic energy converters, turbine generator electric power systems, nuclear rocket engines, and ion and plasma propulsion systems. The use of refractory metals permits higher operating temperatures which means more efficient operation.[7]

Many organizations are active in the refractory metals field. The Refractory Composites Working Group, consisting of individuals concerned with design development and application of refractory composites, represents nearly 50 organizations and companies working in the field. Meetings, sponsored by the Air Force Aeronautical Systems Division and NASA, are attended by 50-70 individuals.[8] The group has concerned itself with all aspects of the refractory metals field, such as coatings, dispersions, strengthening, and plasma spray, as well as efforts to standardize test procedures. Currently the Materials Advisory Board has a refractory metals sheet rolling panel--the purpose: to determine how to produce quality refractory metal sheet. The Bureau of Naval Weapons and the Manufacturing Metals Division, Air Materiel Command manage the contract phase.[2]

AGARD (Advisory Group for Aeronautical Research and Development), consisting of representatives from Canada, the U. S., the United Kingdom, Norway, Denmark, Turkey, Portugal, Federal Republic of Germany, Italy, Greece, Netherlands, Belgium, Luxemborg, and France, has given refractory metals a position of top priority for discussion and has initiated a refractory metals program.[9]

As a result of use of refractory metals in aircraft and missile/space applications, present and proposed, industry has rapidly expanded the number of high capacity, quick acting extrusion presses which are needed for initial breakdown of refractory ingots. Plants designed specifically for the fabrication of refractory metals have been built. These include General Electric's Cleveland facility, du Pont's Curtis Bay plant and Wah Chang's facility in Oregon.[2]

Although no examples of present use of refractory metals by the civilian economy were uncovered in this study, future use of refractories is expected in aircraft engines, other engines where increased efficiency can be obtained with increased operating temperature, nuclear reactors for civilian power, and certain types of heat exchangers.

The study effort found the following examples of expected future commercial use of refractory metals:

Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

mixed carbide fuel material (potential) — A new fuel material, uranium columbium carbide, has been developed at Westinghouse's Astronuclear Laboratory, primarily for use in space auxiliary power and propulsion units. Research was directed toward developing fuel elements which permit higher reactor core temperatures and thus increase the power output capacity of nuclear reactors. Westinghouse sponsored the research with its own funds, although possible missile/space demand was the primary motivation.

It appears probable that these high temperature fuel elements will find application in both existing and new commercial power reactors, according to the company, and will result in lowering unit power generation costs.

refractory alloys (potential) — Several refractory alloys have been developed to meet missile/space specifications. The work has been sponsored by the Air Force and the Navy at the Astronuclear Laboratory and the Central Laboratories of Westinghouse. Other research has been sponsored at the Materials Department of the Astronuclear Laboratories on the forming, machining, and joining of these alloys.

A series of columbium alloys have been developed for high temperature atmospheric exit and entry conditions. In addition, tantalum alloys have been developed with a combination of high temperature and high corrosion resistant properties for use in small compact reactors. Certain of these alloys can be used in temperatures up to 2500°F.

Examples of these alloys are: B-33 Columbium, 4% vanadium; B-66 Columbium, 5% molybdenum, 5% vanadium, 1% zirconium; and T-111 Tantalum, 8% tungsten, 2% hafnium.

While no specific commercial applications have been forthcoming to date for these alloys, Westinghouse believes some of them may have future application in heat exchangers.

2. Maraging Steels

The new ultrahigh strength Maraging steels were in the development and evaluation stage by the International Nickel Company at its Bayonne Research Laboratories in Bayonne, New Jersey, as recently as 1960. Today over 500 tons of the new steels have been produced for sale to commercial and missile/space markets.

Maraging steels are practically carbon-free and contain from 18 to 25 percent nickel as well as other alloying agents. They attain yield strengths of 250,000 to 300,000 psi, while retaining good ductility and toughness. Two heat treatments are required to obtain these properties: heating to 1500°F, air cooling to room temperature, and reheating to approximately 900°F. The last heat is termed "Maraging," which serves to further increase strength and hardness by a precipitation process. Desirable characteristics of these new steels are their exceptionally high strengths, high impact strength, low notch sensitivity, good weldability without pre-heating, hardening without quenching, simple heat treating procedures, and good formability without repeated anneals.

Many of these characteristics make the steels exceptionally attractive for fabricating large rocket motor cases, aircraft landing gears and structural assemblies, shafting, and extrusion dies in tool assemblies. The missile/space industries have been interested in Maraging steels for solid propellant boosters. John Bingham of Aerojet-General presented the results of an evaluation program on Maraging steels conducted in cooperation with International Nickel Company at the Golden Gate Metals Conference in San Francisco. [10]

At the Utica Division of Bendix Corporation, Maraging steels are being evaluated for fabricating a flexible "quill-type" drive shaft for B-47 aircraft. Small diameter shafts deliver up to 85 horsepower at 9,900 rpm without fatigue failures. [10] One reason for selecting the new material for these shafts is its ability to re-age or re-harden to practically full strength without distortions after welding.

Vanadium-Alloys Steel Company of Latrobe, Pennsylvania, now produces Maraging steels under the trade names Vascomax 250 and Vascomax 300. The new steels are available in all customary forms and sizes--from .025" sheet to heavy plate, bars and billets.

The International Nickel Company has applied for patents on the new steels and will grant a royalty-free license to any established concern for production. Maraging steels should find future engineering applications in many shapes and forms where high strengths coupled with unmatched toughness are desired. They should open the way for advanced design concepts heretofore unattainable.

Future applications of Maraging steels are described below.

The International Nickel Company, Inc.
New York, New York

<u>Maraging steels</u>

(potential)

The International Nickel Company has had in the development stage for several years 18 percent to 25 percent nickel, low-carbon, age hardening steels of exceptionally high strength. Good formability characteristics without in-process anneals, as well as ability to be welded without preheating and thoroughly hardened without quenching, made these steels particularly attractive to the missile/space design people for large diameter rocket cases.

NASA has been interested in these steels, but its contribution cannot be considered as significant in the initial development stage. However, NASA did contribute in accelerating the production of thin gages of Maraging steels in two ways. First, it made available the research personnel and testing facilities in the Materials and Structures Division of the Lewis Research Center for a program to assist International Nickel Company in devising test methods to accurately evaluate the properties for maximum performance. Second, NASA represented the availability of an immediate market for thin gage material to be used in the production of large pressure vessels such as the skin of solid propellant missiles. Curtiss-Wright is currently producing experimental rocket cases from thin gage sheet for evaluation purposes.

The major applications of the Maraging steels are not connected with the missile/space program. The steels are used where welding of pre-machined pieces is desired with exceptionally low distortions, or where the controlling factor is weldability in the full hardened condition requiring only a simple post-welding heat treatment. The steels may be adaptable where high strength, low distortion gun parts are required, such as tubes, breech rings, and muzzle breaks. Evaluation studies are underway at various arsenals. One agency has selected Maraging steels for use in hydrofoils now under construction.

* * * *

The missile/space contribution to Maraging steels thus has taken place after the original development of the material. It added to the technology of the material and supplied the initial demand for production of thin gage. The study investigation did not uncover specific non-missile/space use of thin gage, but indications were present that this was about to develop if it has not developed already. The Vanadium Alloys Steel Company reports sales of small quantities of sheet for test and evaluation purposes to a number of commercial manufacturing concerns.

3. Physical Metallurgy

The description which follows is somewhat different and more vague than the preceding ones. It concerns a broad body of scientific knowledge, much of which existed long before the missile/space programs. The contributions of missile/space programs to this body of knowledge are almost impossible to isolate, as are the uses made of these contributions by the commercial sector of the economy. Yet, it appears that the missile/space impact described here is far more significant than that of most other items reported in this study.

Denver Research Institute
University of Denver
Denver, Colorado

physical metallurgy

The field of physical metallurgy deals with the development of metals and alloys and the study of their constitution, structure, and properties. The relation of mechanical and physical properties to the various compositions and the thermal and mechanical treatment of metallic materials, coupled with the underlying solid state principles, provides a more sophisticated understanding of the mechanisms that yield desirable material characteristics.

This work is essential to advance the state-of-the-art, for it produces the technological background that is required in the development of alloys for specific purposes. A perusal of the references cited in any alloy development effort will indicate the necessity for reference to the literature in the field of physical metallurgy to provide a basic understanding of the mechanisms involved.

Federal funds have been available from a number of agencies for many years to support research in this field. A majority of the work is presented in the form of papers at symposiums throughout the country and published in the open literature. If the work is government-sponsored and unclassified in nature, it is also distributed through the facilities of the various government agencies charged with this dissemination.

Additions to the technology of physical metallurgy in most cases cannot be identified as a direct result of a specific program. Basic research usually is not motivated or directed toward this end. However, the new and special demands on metals made by missile/space programs have stimulated and fostered ideas for investigations into specific areas. Concurrently, missile/space requirements have motivated expenditure of funds, both federal and private, to support research into new areas of physical metallurgy. This combination has produced substantial additions to the technology in recent years. That portion of the knowledge thus gained which is unclassified and without proprietary restrictions usually becomes part of the published public literature, freely available to all who may wish to use it.

For these reasons, it is very difficult to assess the value of the contributions made to physical metallurgy by the missile/space programs which, in turn, are transferred and applied to non-missile/space activities. It is a chain reaction, too inter-related and diffused to permit simple observation. In the opinion of the Institute's Metallurgy Division, however, this contribution in the field of physical metallurgy is considerable.

A partially hypothetical example will serve to illustrate this process. Space has produced demand for knowledge of specific heat and emissivity properties of materials for development of re-entry heat shields for space vehicles. The Air Force has sponsored research to determine these properties. Results have been published. Now, assume the hypothetical requirement of a commercial furnace manufacturer for a material to shield the hot section of a high temperature vacuum laboratory furnace. By reference to the property data derived from Air Force sponsored research, he can determine the materials which are most advantageous in his design. Availability of such data reduces guesswork or eliminates considerable research on the part of the manufacturer. No such specific examples of transfer were reported during the study, but it is most probable that these transfers are common.

4. Superalloys

No missile/space contributions to the present commercial applications of superalloys were identified during this study. However, various sources expressed opinion that commercial superalloy applications were receiving missile/space contributions. A brief description of the area seemed appropriate for inclusion, but it is emphasized that no specific items, even in the "potential" category, were identified which met the qualifications of the study.

Superalloy is a name reserved for a group of iron-base, nickel-base, or cobalt-base structural materials developed primarily for high strength properties at temperatures ranging from 1200°F to 2000°F. The evolution of these alloys has coincided with the evolution of the gas turbine engine. The aircraft industry has supplied much of the motivation for their development. However, in recent years demands of the missile/space industry have also provided an impetus for their continued improvement. In commercial applications, these alloys have been widely used in engines for turbine buckets, nozzles, guide vanes, rotors, combustion liners, after-burners, and structural members and fasteners. For space flights, superalloys have been used as the primary structural members on the North American X-15 rocket research planes and as shingles on the outer surface of the Project Mercury re-entry capsule.

Workers at the Mond Nickel Company in Great Britain developed the first series of age-hardenable nickel-base superalloys in 1941.[11] Alloys with better creep resistance were developed by the same group in 1944. About this time, International Nickel Company developed their first age-hardenable alloys in the United States, Inconel X and Inconel W. By 1951, the International Nickel Company had developed Waspaloy and Inconel 700. Work by Bieber of International Nickel Company and Theilemann of Pratt & Whitney Aircraft, among others, resulted in alloys containing both aluminum and titanium.

Improvements in superalloys far out-stripped predictions of the experts in 1950. Temperatures in the range of 1700°F were foreseen, but today it appears that 1900°F may not be the final maximum temperature. It is interesting to note, however, that the significant improvements made since 1952 have come after almost all government support for research was discontinued. Research efforts were continued by industry.[12] Even so, the missile/space industry has given some impetus to the continued development of superalloys simply because it provided a market receptive to minor technological advances. For example, the new Haynes sheet forging alloy L-605 (HF-25) will be used in the lower surface panels of the Dyna-Soar (X-20) hypersonic vehicle where 2000°F temperatures are expected.[13]

5. Epoxy Resins

Epoxy resins were discovered independently and practically simultaneously by researchers in Switzerland and the United States near the end of World War II. Pierre Castan of Ciba in Switzerland and S. O. Greenlee and J. J. Long of the Davoe & Raynolds Company in the United States were awarded the basic patents.[14] In 1945-1946 both companies, Ciba and Davoe & Raynolds, began marketing the epoxy formulations. The output was very small until 1946 when Davoe & Raynolds licensed the process to Shell Chemical Company. At the same time Davoe & Raynolds essentially dropped out of the manufacturing of these resins and became a formulator. Shell and Ciba then became the two largest producers of epoxy resins. Shell does no formulation, however, while Ciba has hundreds of formulations. The 1962 issue of the Modern Plastics Encyclopedia lists 118 suppliers and formulators (there are probably twice this many specialty houses) and 32 large suppliers.[15] Production, from next to nothing in 1946-1947, reached 12 million pounds in 1952 and 60 million pounds in 1960. On a projected basis, it is estimated that 100 million pounds will be produced by 1965.

Epoxies as a material can have a variety of properties, and no specific set of properties should be ascribed to the class. Epoxies can be of very high molecular weight. The formulations, a million of which are conceivably possible, can produce very hard finishes or yield elastomers depending on the use of a flexibilizer. Specific formulations, sometimes requiring considerable time for development, are required for specific applications.

Epoxies can be any one of many resin molecules that are polymerized through the interaction of monomers (the simple unpolymerized form of a compound). Theoretically, epoxies can be synthesized from numerous materials. As a practical matter, most commercial epoxies are a combination of epichlorohydrin and bisphenol A. These materials are cooked under pressure by the epoxy manufacturer until they are partially polymerized, that is, until their combined molecular structure is composed of long chains of atoms with each chain terminating at one or more points in an epoxide group containing a reactive oxygen atom.

The characteristics of the epoxy at this point depend on many factors: the temperature, the pressure, the length of cooking time, and the basic materials used. Each of the manufacturers of basic resins produces a variety of resins for various purposes. In general, the manufacturers all produce similar lines.

Although the basic resins contain most of the inherent qualities of a completed epoxy system, they are chemically stable, have an indefinite shelf life, and are useless by themselves. A liquid epoxy resin will remain a liquid until a compatible curing agent or hardener is added to it. A flexibilizer must also be added in some cases. While an unmodified epoxy compound might well do everything it is supposed to do, generally it will be too brittle to be of value. For further modifications to meet specific purposes or conditions, it is also possible (and often desirable) to add one or more materials that serve as pigments or dyes, fillers or dilutents, accelerators or extenders.

An early use of these epoxy adhesives was in airframe construction where their applicability was proven for bonding aluminum-to-aluminum as well as for bonding many other materials. Additional applications were recognized as missile/space requirements materialized.

These more stringent requirements have stimulated the development of new formulations, as can be seen in the following examples:

Dyna-Therm Chemical Corporation
Burbank, California

<u>heat resistant materials</u>

(potential)

Dyna-Therm produces heat resistant paints, coatings, and foams which have found their greatest use in the missile/space program. The initial development of most of these products came prior to missile/space emphasis and was funded by the company. However, their use in missile/space helped further their development. The prime contractors for the Atlas, Titan, Minuteman, and Saturn programs, as well as the subcontractors installing the launch facilities, have used these materials. The main uses of Dyna-Therm's products in the programs are in protecting both the vehicle and the launching pads from the extremely high rocket temperatures experienced during rocket launchings.

The first of these is Flamemastic(R) 700 Thermal coating. It is a mastic composition containing thermoplastic resinous binders, flame retardant chemicals, and heat resistant reinforcing fibers. This material has been in production for the last five years and protects against high velocity combustion heats of over 3000°F with a film thickness as low as .032". For example, where unprotected metal surfaces have a temperature range of 1300°F to 1400°F with the application of a gas flame, Flamemastic protected metal has a temperature range of 200° to 265°F. The coating may be brushed or sprayed on. Commercial applications for which this material appears practical include its use as a chemical resistant coating on structural steel in chemical plants and foundries, and as a non-skid, fire-retardant, corrosion-resistant coating on the decks of tankers.

A second material is D-100 Foam, a two-part, rigid flame resistant polyurethane foam designed to withstand extremely high temperatures. It may be used not only for protection of missile launching pads and apparatus, but also for flame resistant paneling, fire doors, and high heat honeycomb structures. It functions as a protective shield against temperatures as high as 10,000°F. The company anticipates that as production increases the price can be substantially reduced, making it more attractive for commercial uses.

In the future, Dyna-Therm hopes to make these products available for use in a wide range of commercial applications including fire walls, furnaces, and laboratory equipment.

Fiber Resin Company
Burbank, California

sub-zero hardening epoxy resin

The Fiber Resin Company began as a franchised distributor of Kish Epoxy Resins but the rapid growth of the missile/space industry in Southern California has led it to do its own formulating. Sub-zero hardening epoxy resin is an example of a material developed originally by Fiber Resin for the missile/space effort, which the company feels will almost certainly have wide commercial application. This epoxy resin can be used for bonding, patching, coating, or waterproofing. The material was developed originally for bonding and patching steel sandwich material, used in housing anti-missile radar in the Arctic.

To date, the resin has found commercial use in repair and patching of new and old concrete in several docks and flood control canals in the Northwestern part of the United States. As an example of potential commercial use, a telephone company is interested in this resin as a repair material that can be used during the winter. The commercial sales volume to date of this material is approximately $100,000.

Joseph Waldman & Sons
Epoxy Products Division
Irvington, New Jersey

epoxy molding, materials, encapsulation cups, and silver-filled epoxy materials

Epoxy molding materials and encapsulation cups were developed shortly after World War II independent of the missile/space program. At that time, however, costs were high due to limited commercial markets. With the missile/space build-up, a large demand for these materials and products developed. This allowed the economies of mass production to be shared by the industrial and consumer electronics markets.

Epoxy products and materials are used for electronic and electrical insulation of components in guidance, communication, and computer systems in the missile/space program. Commercial uses are similar, with applications in packaging of electronic components for computers and other industrial electronics, in radio and television, and in automotive electrical systems.

The development of these products was funded mainly in-house while missile/space technology information was often supplied by a prime space contractor, subcontractor, or government agency.

6. Miscellaneous

Navan Products, Inc.
Subsidiary of North American Aviation, Inc.
El Segundo, California

Tens-50 aluminum alloy

The aircraft and missile/space industries have continuing need for high strength-to-weight materials, including high tensile strength aluminum. However, small iron impurities in aluminum alloys have been troublesome since they produce relatively brittle properties in the alloys. The aluminum industry sought to solve this problem by directing its efforts toward a high purity program. Many foundries, however, experienced difficulty operating to the required standards of purity.

Scientists at North American Aviation approached the problem differently and developed about six years ago Tens-50 (Tensile 50,000), an alloy of aluminum and beryllium. According to the company, this alloy requires no more purity than is standard in the typical aluminum foundry, but gives the highest tensile strength achievable by casting to date.

On a special order basis, Navan obtained Tens-50 from aluminum producers and began promotional marketing in 1957 to users of high strength-to-weight metals. Once demand for Tens-50 had been established, Navan licensed it to the aluminum industry for manufacture and sale. Navan has licensed the Reynolds Metal Company and the Aluminum Company of America under Patent No. 2,908,566.

The original motivation for the research which led to development of Tens-50 came from the requirements of supersonic aircraft for increased strength in aluminum casting alloys. The subsequent demands of missile/space programs provided part of the impetus for additional research on the basic alloy, designated 42B. This further research led to development of other versions of the alloy, A357, 358, and A358, which contain smaller percentages of beryllium. They are substantially lower priced than Tens-50 and hence more attractive, especially to the commercial market.

In addition, missile/space demands for casting have stimulated developments in foundry techniques of Tens-50. The Rocketdyne Division of North American developed a super-chilling technique during the casting process to produce higher quality casting. Rocketdyne uses Tens-50 in its pump castings for liquid fuel rocket engines.

Navan reports that Tens-50 has been used in a variety of non-missile/space applications including heavy duty automobile and truck wheel castings, cement truck bodies, railroad cars, and oil fuel pumps.

* * * *

The missile/space contribution in this case was not the original development of the alloy; rather it was part of the stimulus for subsequent development work leading to other and more commercially feasible versions of the alloy, plus improved foundry techniques.

The Reynolds Metal Company sponsored research in-house on Tens-50, which led to A357, 358, and A358. According to the company, the motive behind this effort was the desire to lower the price of Tens-50 to increase its market potential. Missile/space requirements for high strength-to-weight materials, along with commercial applications, represented the market potential. To date, most of Reynolds' sales have been of Tens-50, but it has produced and sold A357 and 358; no sales have been made of A358.

An article by S. T. Abbate and R. A. Zuech describes Rocketdyne's test program on heavy chilling of molds in casting Tens-50.[16]

Other sources report that Tens-50 has been used for several years in a variety of non-missile/space applications, such as housing for torque wrenches, holding brackets and adapters for aircraft engines, instrument cases, and components for aircraft ejection seats.

The Aluminum Company of America also is currently producing ingots and castings of Tens-50.

General Electric Company
Chemical and Metallurgical Division
New York, New York

<u>pyrolytic graphite</u>

(potential)

Pyrolytic graphite is a form of carbon having unique high temperature properties and is produced by the deposition of carbon from a vapor phase onto a substrate. It possesses a high degree of anisotropy--its physical, electrical, and thermal properties in one plane differ substantially from the same properties in a perpendicular plane.

Original work on pyrolytic graphite goes back to the last century. In 1879-1883, patents were issued to W. E. Sawyer and T. A. Edison on the formation of pyrolytic graphite. These patents resulted from work on the treatment of carbon filaments to improve their uniformity and mechanical properties. Scattered investigation in this field continued. In the 1930's, pyrolytic graphite (sometimes referred to as "bright carbon") was considered for coating electron tube parts, but the graphite itself was available only as film coatings or as a powder. Its anisotropy was apparently never considered important; the powder could not be specifically oriented. In the mid-1950's, some work was done on pyrolytic graphite for coating nuclear fuel elements, especially powder types.

Early in 1958, the General Electric Company started investigating techniques for making large free-standing shapes of pyrolytic graphite for use as nosecones. The Missile and Space Vehicle Department at Philadelphia cooperated with the G. E. Research Laboratory with funds from Air Force contracts AF-04(645)-24, AF-04(647)-269, and AF-04(647)-486, and set up facilities at Philadelphia to make pyrolytic graphite for its own experimentation, including studies of its applicability to nosecones. Activities in the pyrolytic graphite area have continued at MSVD and current contracts which contribute some support to these activities are NOW 61-0481-C-FBM and AF-04(647)-617, both of which are classified.

G. E. has also continued to carry out investigations in the pyrolytic graphite area. Most of this activity has been carried out with company funds although some of it has been done under the above identified Air Force contracts. G. E. also performed a small amount of measurement work in the pyrolytic graphite area with funds under AEC contract AT(45-1)-1350, administered by the Hanford Atomic Products Operation.

The Specialty Alloys Product Section of the Metallurgical Products Department became interested in producing pyrolytic graphite in the last quarter of 1959 and had their first production facilities installed about June 1960. Most of their pyrolytic graphite sales have been as an R & D material, primarily for use as a thermal shield or rocket nozzle in space applications. To date there have been only token commercial sales of the material to determine its suitability for commercial and industrial applications.

Pyrolytic graphite has a number of potential commercial applications but the Metallurgical Products Department believes that such applications are still some three years off. Such potential applications include uses requiring thermally or chemically resistant refractory materials, such as furnace components, or as piping or crucibles for coating molten metals or caustic solutions. There are also a number of possible applications in the electronic and electrical fields, e.g., use in frequency filters, thermistors, high temperature capacitors, time delay mechanisms, and variable fuses.

* * * *

Graphite's distinguishing characteristics are the highest service temperature of any elemental solid, and low density. Pyrolytic graphite--really a class of materials rather than a single material--is characterized by its thermal anisotropy. Along the layer plane, pyrolytic graphite is a semi-metal, electrically conductive and more thermally conductive than copper. Perpendicular to the layer plane, the carbon atoms are loosely bonded and pyrolytic graphite is a thermal insulator. Other properties of pyrolytic graphite include oxidation resistance and impermeability. Pyrolytic graphite has several disadvantages in that it is difficult to fabricate, expensive, and develops localized high stresses upon rapid heating.

A number of organizations besides General Electric are working on pyrolytic graphite, including Raytheon, Lockheed Aircraft Corporation, High Temperature Materials, Inc., and National Carbon. About 10 years ago, flat specimens of pyrolytic graphite were produced by Brown and Watt at the Royal Aircraft Establishment.

Much progress has been made in recent years in developing pyrolytic graphite and its new alloys for practical use. However, work remains to be done in understanding further its physical properties and in developing fabrication techniques. Also, its current high cost acts as a limiting factor except in special applications. Nevertheless, its unique properties seem to hold substantial promise for commercial as well as missile/space uses. Its potential for solving many of the difficult problems posed by nuclear propulsion in space should act as a stimulus for continued interest. These comments are based on an article by Claude A. Klein in International Science and Technology.[17]

The Marquardt Corporation
Van Nuys, California

materials test equipment

In 1956, Marquardt Corporation found it necessary to determine the mechanical properties of materials subject to rapid temperature rise and rapid application of load in connection with work being done on the ram-jet for the Bomarc missile. Marquardt surveyed the field and found that no one had a testing device which would do the job. Under DOD funding, a prototype automatic, servo-controlled materials testing machine was built. This was the first application of true servo control to materials testing, according to Marquardt. It is significant because metallurgists have found that the rate of testing is extremely important. For example, some materials shatter under the rapid application of load while the same material would merely bend under slow application of the same load.

Marquardt decided there must be a need by other firms for similar test equipment. In 1958, the decision was made to spend company money to make and sell this test equipment on a fixed price basis. The initial marketing was quite limited during the period 1958-60, but in 1961 the marketing effort was accelerated. The machine as offered included an automatic programmer and an instrument for accurately measuring strain at temperatures up to 5000°F.

Still not satisfied, Marquardt, using the basic principles developed in the original machine, built new models of different capacities with additional company funding. The automatic programmer was redesigned, and a servo control unit as well as other accessories were developed to make a product line. The new line of machines equipped with the automatic control console provides automatic programming, linear rate programming, and automatic simulated calibration of load. This extends the capability of the equipment for ease of operation by technicians in running tension, compression, transverse, fatigue, creep, relaxation, and cyclic tests.

These machines are now being purchased primarily by research laboratories for basic metals research. Prices range from $25,000 to $57,000.

Calumet and Hecla, Inc.
Flexonics Division
Bartlett, Illinois

metal hose

Calumet and Hecla's Flexonics Division has improved one type of metal hose used in the extreme environmental conditions of missile launching and essentially made an innovation in another type.

Operating characteristics imposed by the missile/space program required improvements in the design of a product which Flexonics had been making for several years: an interlock type, flexible metal hose. The improved design provides increased limits of axial extension and compression. In the missile/space program, this flexible metal hose is used as internal liners for fuel, liquid oxygen, and other ducting systems to eliminate or reduce turbulence in the flowing fluids. Otherwise, the hose is used in ducting systems in commercial and military aircraft.

A new corrugation process facilitates the manufacture of a second hose, a multi-ply corrugated metal hose. Development was initiated to make a better product using metal hose, as opposed to Teflon or other synthetic hoses, as a normal course of company product improvement. However, the missile/space program demands were an impetus and, in some cases, further defined desired product specifications. The result was a hose with improved operating characteristics in the areas of high temperatures, high pressures, life cycling, and resistance to impulse pressures.

This product has found missile/space uses in hydraulic and pneumatic lines where motion, vibration, and impulse are a consideration. According to Flexonics, there have been commercial applications in aircraft and atomic power facilities, and more industrial uses are anticipated in the future.

The development of both of these metal hoses was funded by the company.

Douglas Aircraft Company
Aircomb Division
Santa Monica, California

Aircomb

Aircomb is a honeycomb structure of kraftpaper, impregnated with a phenolic type resin for strength and resistance to environmental factors. It was developed by Douglas for the first Nike program in the late 1940's and is currently used in the fabrication of missiles, space vehicles, and ground support equipment. In use, it is sandwiched between faces of thin material, such as aluminum, plywood, wood, stainless steel, magnesium, or porcelain-enameled steel.

Because of the nature of sandwich construction, it lends itself to such structural uses as floors, walls, roofs, and box sides requiring high local crushing strength. In addition to shear strength, the ability to carry compression floor loads normal to the faces is a necessary requirement of core material. Douglas Aircomb is capable of carrying as much as 25 tons per square foot.

Aircomb has many commercial uses. Boat manufacturers are using it for hull reinforcement, decks, partitions, seats, and topside structures. It is being used in new buildings for both exterior and interior applications such as curtain walls and decorative panels. In aircraft, it is used for tables, partitions, shelves, cabinets, and exterior access doors. New commercial uses are being developed through a continuing R & D program.

A separate division was established in July 1962 to manufacture Aircomb.

Solar Aircraft Company
A Subsidiary of International Harvester Company
San Diego, California

all metal insulation

Solar Aircraft Company has developed an all-metal insulation made with sandwich type construction of outer metal facings with a number of core laminations of embossed metal foil. It is radiation damage resistant, will withstand rapid gas pressure changes, and will not contaminate nuclear reactor cooling gases. In addition, it has a low conduction factor with the necessary stability to retain its thermal properties throughout the life of a nuclear reactor without maintenance or replacement.

Concepts developed for lightweight rocket motors and space heat exchangers were utilized in developing this by-product. The work which resulted in the Solar all-metal insulation was conducted as a general rocket nozzle R & D project. The resulting technology has since been applied to the Nike, Ranger, and Atlas missiles.

The insulation is presently used for internal nuclear pile insulation in gas cooled reactors. Anticipated commercial applications include high temperature insulation for hot piping, steam generators, and turbomachinery.

H. MEDICAL TECHNOLOGY

Several items have been identified in the course of this study which constitute missile/space program contributions to advances in medical technology. Most of these items, although not necessarily the most important ones, are in the field of medical electronics.

Electronics has steadily become more important in the medical field. Starting with the first electrocardiographic studies by Kolliker and Muller in 1858, electronic principles and instruments have been utilized in many areas of medical research, diagnosis, and treatment. Today, many researchers in what is often called the "life sciences" are looking to electronics to see what new methods and techniques can be applied to their field. One gage of the importance of this is the estimate that the field of biological and medical instrumentation and electronics currently has an annual market of about $500,000,000.[1]

The impact of missile/space programs on medical electronics is extremely difficult to determine, but it has been felt in two ways. First, and most directly, the programs have required the development of certain specialized equipment. Placing man in the harsh environment of space requires that his physiological responses be monitored carefully, necessitating the development of data gathering and telemetry systems. These systems permit considerable freedom of action during the period of monitored response, since no wires are used. Some of these devices are now finding non-space application.

The second way in which the space program has aided medical electronics is more indirect. The emphasis on extreme reliability and continued miniaturization has made equipment more readily available in the field of medical electronics, where these features are also highly desirable.

A recent series of articles describes much of the current activity in medical electronics.[2] It is apparent from these articles that the majority of the work in the medical electronics field is being conducted by organizations not directly associated with the space program. However, some contribution from space activity is apparent.

In addition to the contribution of electronics, there is another area where the space program is having an impact on medical technology. The rigors and uncertainties of space flight require that only the most physically and mentally qualified trainees be accepted as astronauts. This requirement has aided in the development of new techniques for evaluating the physical and mental capabilities of prospective astronauts. It is anticipated by those working in this field that these developments will have considerable non-space transfer and will be of long-term importance.

Examples of transfer follow.

Lovelace Foundation for Medical Education and Research
Albuquerque, New Mexico

<u>improvements in medical examination and other medical techniques</u>	The Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico, has examined applicants for pilot and astronaut selection for a number of aerospace programs. The most extensive and widely known of these efforts was the screening of astronaut candidates for Project Mercury, the NASA manned

space flight program. Similar projects have included pilot selection for other NASA programs and flight surgeon services for test pilots at the Flight Research Center at Edwards AFB, California. The Foundation also has been commissioned by NASA (Contract NASR 115) to develop a system for acquiring, evaluating, and disseminating all available information on bio-astronautics, the medical arts applicable to space programs. This project is now underway.

The Lovelace Foundation is immediately connected, by staff relationships and physical proximity, with the Lovelace Clinic and Bataan Memorial Methodist Hospital. This simplifies the transfer of new medical service techniques from research to clinical application.

A unique examination system developed for the Mercury Astronaut program at the Foundation was the routine application of dynamic physiological tests developed in-house, supplementing the conventional static tests ordinarily employed in physical examinations. These tests are now being used extensively on regular clinic patients at the Lovelace Clinic and elsewhere. Another innovation was the recording of all pertinent medical data directly on punch cards by a system previously developed by Dr. A. H. Schwichtenberg of the Lovelace Foundation staff under USAF sponsorship.[3]

Other techniques refined to an exceptional degree in the Mercury program included: 1) unusually exhaustive examinations, with careful coordination of many specialists, unusually detailed histories, and more contact than usual between the doctor and the patient; 2) improved X-ray control procedures made important by extensive radiological examination, leading to wide use of intensifying screens, video taping of X-ray images, and use of higher voltage X-ray equipment resulting in shorter exposures; and 3) the use of micro-sampling of blood for laboratory examinations beyond the limits previously considered feasible.

Possibly the most significant contribution of this space-related research project is the indication that this form of dynamic examination, or examination of physical capability under conditions of environmental stress, holds promise for the objective measurement of physiological aging. Follow-up research on this Physiological Aging Rating Project is underway at the Foundation, at George Washington University, and at the Civil Aeromedical Research Institute. One of the immediate needs for such measurement is determining appropriate retirement ages for pilots and others whose jobs will not permit performance deterioration resulting from aging.

More immediate, feasible uses of these dynamic examination techniques are thought to include determination of the physical capabilities of people recovering from heart surgery, and evaluation of physical disability claims in Workmen's Compensation cases.

Lovelace Foundation staff members also attributed to unidentified space research programs such medical innovations as those described below, about which they have heard but of which they have less direct knowledge. (Denver Research Institute has not documented the following examples. However, the Lovelace Foundation staff is in an excellent position to be aware of medical developments, and therefore these examples are presented to show possible additional contributions of missile/space research.)

The USAF is reportedly sponsoring research into computer programming methods which will permit non-medical personnel (those in a small spacecraft, for instance) to feed into a computer evident symptoms and quantitative data such as temperature, pulse, and results of simple laboratory tests. The computer will then diagnose the condition and select an appropriate treatment.

It is suggested that research on closed life support systems will lead to earlier detection and identification of toxins in the air and in the human body. This area of research may also lead to greater understanding of the effects on human life of such environmental factors as ions of different polarities and trace elements in the atmosphere. Finally, it is suggested that this research may furnish improved medical care techniques involving low-residue diets and disposal of body wastes.

There is general agreement that defense and space research have led to greatly increased reliability in instrumentation. Instances of this include the suggestions that better control of oxygen and other continuous medication is possible, and that electronic reliability in miniaturized electronic packages has facilitated development of small sensors and specialized devices such as self-contained, portable heart pacemakers.

Finally, it is suggested that some of these innovations will probably lead to substantial institutional changes in the medical service industry. If computers and electronic instruments assume added importance in diagnosis and treatment, the capital requirements for medical practice will probably increase. Physicians will also need (or require access to) knowledge of such things as information theory, electronics, and computer technology, if they are to properly use these new tools.

Telemedics, Inc.
A Subsidiary of Vector Manufacturing Company
Southampton, Pennsylvania

RKG 100 radio-electro-cardiograph

The science of electrocardiography--analysis of the electrical activity of the heart--has been one of the keystones of cardiac diagnosis for half a century. However, because the patient had to be connected by wires to the recording apparatus, the doctor generally was limited to finding out how the heart acted while the patient was resting. Development of radioelectrocardiography, the broadcasting of the EKG waves from the patient to recording apparatus with no connective wires, now permits the doctor to gather previously inaccessible data.

The concept of radioelectrocardiography was first published 13 years ago as a result of experimental work done by the United States Air Force. It remained in this experimental class until Telemedics introduced its RKG 100 radioelectrocardiograph to the medical profession in May 1961 at the annual meeting of the American College of Cardiology. This was the first radioelectrocardiograph made available commercially to physicians.

The RKG 100 is a direct descendant of the equipment originally developed by Telemedics' parent, Vector Manufacturing Company, for use in the rigorous testing program undergone by NASA's astronauts. Reactions of the hearts of the astronauts to the pressures of gravity, acceleration, and deceleration were determined with this equipment in the centrifuge at the United States Naval Air Development Station in Johnsville, Pennsylvania. Following its successful use with the astronauts, Vector established the Telemedics Division to adapt the radio-electrocardiograph for use by practicing physicians.

The RKG 100 is a miniaturized very high frequency broadcasting system, consisting of specially designed electrodes, a transmitter, and a receiver. The electrodes are of a Band-Aid type which adheres to the surface of the skin. The RKG 100 transmitter, the unit carried by the patient, is a little larger than a pack of cigarettes. It is transistorized and operates on self-contained rechargeable batteries. The entire unit weighs 10 ounces. The transmitter can be placed in the patient's pocket or clipped to his belt as he goes through the examination. The unit has a range of up to 1,500 feet on a VHF authorized and approved by the Federal Communications Commission. The RKG 100 receiver is smaller than a typewriter. Controls enable the EKG waves received to be channeled to a standard electrocardiographic recording apparatus, an oscilloscope, or a magnetic tape recorder, or all three simultaneously.

The company feels that the applications for the RKG 100 are many and varied. Its prime use to date has been for the examination of more than 10,000 patients during exercise. Many of these studies have been conducted by Dr. Samuel Bellet, Chief of the Division of Cardiology of the Philadelphia General Hospital. A recent article by Dr. Bellet, et al., gives an excellent bibliography covering the background and use of radioelectrocardiographic devices.[4]

Beyond conducting regular exercise examinations, the RKG 100 is being used for a variety of purposes. At Lankenau Hospital in Philadelphia, patients who have suffered heart attacks are studied for a few days after their seizures to determine effects of the slightest exertion. It is hoped that this will lead to improved recuperation programs. At Lankenau and in New York Hospital, the RKG 100 is used to monitor the heart during delicate X-ray procedures in the course of which a dye is injected into the heart. Since the radioelectrocardiograph broadcasts on VHF, it is above the electrical interference caused by the X-ray equipment. This is a very definite advantage over conventional electrocardiographs which operate on the house wiring of the hospital and are, therefore, subject to considerable electrical interference and distortion originating from many appliances in the institution. At Montefiore Hospital in New York, heart patients are monitored during rehabilitation and exercises to see that their capabilities are not exceeded. The equipment has also been used to monitor the heart during surgery, recovery, intensive care, and electro-shock therapy.

A new field opened up by this equipment is that of environmental testing--recording the cardiogram under natural conditions. The Bell Telephone Company of Pennsylvania, which is using the RKG 100 in its Management Physical Examination Program, intends to take the EKG's of some of its executives during conferences and other office activities in which stresses might be present.

The RKG 100 is now being used in more than 40 locations in the United States and Canada. Installations other than the ones previously mentioned include: the Federal Aviation Administration; Johns Hopkins; Mayo Clinic; Walter Reed Army Medical Center; Ohio State, Oklahoma, Georgetown, and Howard universities; Veterans Administration hospitals in Maryland and Illinois; and the Beverly Hills Medical Clinic. Private physicians in several states are also using it.

The company feels that there is a genuine need for this kind of equipment in medical practice. Its research efforts are continuing toward development of related medical electronics equipment which will fill gaps now existing in other aspects of patient care.[5]

Massachusetts Institute of Technology
Cambridge, Massachusetts

GDM viscometer

A device used in making inertial guidance systems for the Polaris missile has turned out to be a valuable medical research tool for studying blood and blood viscosity. The device, an ultrasensitive instrument for measuring very small torques, or twisting forces, was invented at the Instrumentation Laboratory of MIT, where the Polaris inertial guidance system was developed.

The device was invented by Philip J. Gilinson, Jr., Electromagnetic Coordinator at the Instrumentation Laboratory, and Charles R. Dauwalter, a laboratory engineer, as a testing tool to aid in developing gyroscopes used in Polaris guidance systems. Several industrial firms, manufacturing Polaris gyros according to MIT designs, use testing instruments similar to this device. The instrument, called a "torque-to-balance loop," is used to check with extreme precision the performance of gyroscopes and gyro sub-units. It is so sensitive to torque that it can measure the rotational force exerted by a small wheel that turns only once a day.

In medical research, the instrument is called the "GDM Viscometer" after its developers--Gilinson, Dauwalter, and Dr. E. W. Merrill.

Major advantages of the device as a viscometer are that a test requires only a teaspoon of blood (4 cubic centimeters) and can be performed in less than a minute. Most viscometers, using different principles, require far more blood and so much time that the blood sometimes clots before a test can be completed. As a viscometer, the device is rigged to a small cup containing fluid to be tested. A rotor, turned by a torque motor, is immersed in the blood. The particular motor used is capable of turning the rotor with an extremely slow but constant speed. The operator can change speeds to obtain viscosity readings at different flow rates. The rotor, when turned, exerts shear on the fluid at a known rate--known, that is, because it results from the particular motor setting used. The shear rate is analogous to the flow rate and causes a shear stress in the fluid which, in turn, exerts a torque on the cup containing the fluid. The GDM viscometer measures the torque on the cup with extreme precision and, knowing this torque, the researchers are able to compute the shear stress that produced it. Shear rate, known from the motor setting, and shear stress, read as torque by the viscometer, serve as the bases for computing viscosity.

The value of the GDM viscometer is its capability of imparting very tiny shear rates to the blood being tested and of measuring with great precision the equally tiny shear stress that results, making possible viscosity studies at low ranges of shear rate and stress never before attainable. Shear, or flow, rates of fluids are measured in inverse seconds while viscosity is measured in centipoise. Most viscometers can accurately measure viscosity of watery fluids like plasma under shear rates down only as low as 20 inverse seconds. The GDM viscometer can measure viscosities under shear rates as low as .1 inverse seconds--or 200 times lower than ordinary viscometers.

Ordinary viscometers have shown that viscosity of blood plasma remains at approximately 1.5 centipoise under shear rates as low as 20 inverse seconds--the lower minimum accuracy range of most instruments. This constant viscosity with reducing shear rate has lead to the general assumption that plasma is Newtonian. Previous studies by Dr. Roe E. Wells, Jr., associate in medicine at Harvard Medical School, and Dr. Merrill, using a viscometer less sensitive than the GDM device, gave a hint about the possible non-Newtonian nature of plasma and caused them to seek a more sensitive instrument. Studies with the GDM viscometer have produced data showing that as the shear rate is lowered to the range of .1 inverse seconds, plasma viscosity jumps to as high as 18 centipoise. These are the findings that led the MIT and Harvard investigators to the conclusion that plasma is, in fact, non-Newtonian. An understanding of the non-Newtonian character of blood plasma is an important piece of fundamental knowledge. Drs. Merrill and Wells believe it might help explain some of the curious mechanics of blood circulation in capillaries, the body's smallest blood vessels.

The Boeing Company
Associated Products Division
Seattle, Washington

<u>physiological monitoring system</u>

(potential)

The Applied Research and Development Laboratory of the Boeing Company has developed an instrument system to monitor the physical condition of human beings without seriously restricting their capability to perform normal operations. Development of the initial system began in 1959 and was completed about six months later. Subsequent improvements have been made.

The system contains a series of electrical preamplifiers receiving signals from physiological sensors. The amplified signals are transmitted to the recording or readout devices by either wire or telemetry. The system consists of a miniaturized EKG preamplifier, a phonocardiograph, and a respirometer. The preamplifiers are devised to work simultaneously or individually. Devised for studying physiological changes under controlled environmental and physical conditions, the preamplifiers seem applicable to clinical research.

Motivation for development of the system stemmed at least partially from the Air Force's Dyna-Soar program (X-20).

The system has been licensed to the Arnoux Company by Boeing's Associated Products Division. Arnoux is continuing further developmental work with the aim of marketing the system for general application by hospitals, doctors, research laboratories, and universities.

<u>oxygen consumption meter</u>

(potential)

A second device developed by the Boeing Company is an oxygen consumption meter. Like the system described above, the motivation for this development is partially attributable to Boeing's participation in the Dyna-Soar (X-20) program. The item was developed to measure the amount of oxygen a person would consume under simulated flight conditions. Equipment then available to perform this task was not sufficiently accurate for the company's purpose.

A closed system supplies oxygen from pressure tanks through a regulator to the patient or subject as demanded. Expired air is circulated through a carbon dioxide and water-absorbing system which permits the unused oxygen to pass through for re-use. The amplitude, frequency, and pattern of breathing are sensed by a temperature thermistor in the gas passage tube. This information can be used on a recorder or visual readout-type counter. The volume of oxygen consumed is derived from calculation of pressure changes as observed on the tank gage with correction for temperature. The meter provides minute-by-minute rate of oxygen consumed and is accurate within ± 1 percent of oxygen consumed.

The device has been licensed to the Arnoux Company, where further development is being carried out to prepare it for commercial use. A potential commercial application is its use to measure the capability for work or activity of a person recovering from a heart attack.

Douglas Aircraft Company
Diversified Products Department
Santa Monica, California

As the result of developments connected with its missile/space programs, Douglas Aircraft has recently placed several products on the commercial market.

<u>electronic cancer thermometer</u>

The first, an electronic cancer thermometer, was developed to provide accurate monitoring of temperatures in cryogenic therapy. One technique in cancer treatment involves the use of liquid nitrogen for freezing of tumors. In this process it is important that the area surrounding the tumor be instrumented to provide the physician with rapid and accurate information on cold penetration. Through sensing probes encased in hypodermic needles, this unit registers temperatures through a temperature span of 240°C, from -200°C to 40°C with errors of less than 2°. Six separate probes and indicators are encased in one cabinet, each one being color coded for easy reference..

<u>electronic stethoscope</u>

An electronic stethoscope was designed to give physicians the same hearing quality as present units but with many times the hearing power. Frequency control allows concentration on heart or lung sounds as desired. Volume control aids in making faint heart sounds clearer. Weighing six ounces and less than six inches long, the instrument attaches to physicians' existing headsets. It is transistorized and uses a standard transistor radio battery.

<u>electronic thermometer</u>
(potential)

Douglas has also made several prototypes of an electronic thermometer which has a digital readout device providing readings accurate to 1/4 of 1 percent of the full scale of 40°. This transistorized, battery powered unit weighs approximately one pound. It is a self-balancing indicator which will provide readings in less than 20 seconds.

The devices developed and marketed by Douglas' Diversified Products Department have all been funded by Douglas.

I. RE-ENTRY SIMULATION -- The Plasma Jet

A plasma jet is a device for creating a very high temperature gas jet--much hotter than can be produced by a chemical flame.

To understand the plasma jet's principle of operation, consider the ordinary electric arc. A large voltage potential between two electrodes across a gas-filled gap will cause a few of the electrons at the negative electrode to break away and be accelerated across the gap by the potential difference. Most of these electrons will collide with gas atoms or molecules, causing some ionization of the gas. As ionization takes place, more electrons can flow across the gap. Soon the gas in the space between the electrodes is quite ionized and quite conductive--with electrons flowing across the gap in one direction and positive ions flowing across in the other. Heating takes place as the colliding electrons, ions, and atoms give up some of their kinetic energy in the form of heat energy. Ions recombining with electrons also cause heating.[1]

Temperatures reached by this process are near 7,500°F. Merely increasing the electrical current through the gap will increase the volume of heated gas but will not increase the temperature appreciably. However, increasing the density of the gas, thereby increasing the probability of collision, will tend to increase the temperature. In a plasma jet this increase in density takes place by the "pinch" effect. The first, or thermal, pinch effect is a by-product of the need to cool the chamber in which the plasma jet operates. Cooling tends to decrease the ionization, and the conductivity, of the outer layers of gas. The current flow then tends to concentrate in the center of the discharge, causing increased current density and more heating.[1]

The second, or magnetic, pinch effect is a result of the demonstrated tendency of two parallel conductors, each conducting in the same direction, to be attracted to each other by their own self-induced magnetic fields. Similarly, the charged particles flowing between electrodes are routed together by their own self-induced magnetic field. This causes the density of the gas in the discharge to increase which in turn causes more heating.[1]

While the hottest theoretical temperature which can be achieved by a chemical flame is 10,000°F, plasma jets now made can reach 30,000°F. In practical operation, the gas is usually forced through a gun which contains the electrodes so that the heated plasma is ejected in the form of a jet.

Although there are many methods of stabilization of the plasma jet, the basic principle of operation remains the same.

Patent applications and articles describing work on ancestors of the plasma jet can be traced as far back as 1900.[2] H. Gerdien of Germany built the first plasma generator to maintain operation for more than a very short period of time in the early 1920's.[1] Irving Langmuir laid the theoretical foundations of plasmas in the 1920's and applied the word "plasma" to the ionized gas in 1928.[3]

Interest in the field broadened in the 1930's, but in the 1950's the missile/space field, with its requirement for means of working with and testing high temperature materials for rocket nozzles, caused rapid development.[2] In addition, high pressure air at temperatures of over 6,000°F was needed to produce the stream of high velocity room-temperature gas needed for simulated re-entry at high altitudes. This in turn stimulated the development of the plasma jet.

Practical plasma torches were first operated in about 1956.[2] Early work was done by both the Knolls Research Laboratory of the General Electric Company and the Plasmadyne Corporation of Santa Ana, California.[1] A few articles were cited on the plasma jet in the Applied Science and Technology Index of 1957 and 1958, but not until 1959 did many articles on the subject appear. Companies presently doing work in the plasma jet field include: The Plasmadyne Corporation, The Linde Division of Union Carbide, the Thermal Dynamics Corporation, the Plasma Tech Division of the Valley Metallurgical Processing Company, Inc., Metco, Inc., the Norton Company, and the Industrial Products Subdivision of Avco Corporation.

Plasmadyne Corporation
A Giannini Scientific Company
Santa Ana, California

plasmajet — A gas in an extremely hot, ionized state is called a plasma. It is a mixture of free electrons, positive ions, and neutral atoms; all molecular bonds are broken. A plasma may be formed in many ways. For example, a nosecone re-entering the earth's atmosphere is surrounded by a plasma created by the high temperatures caused by air friction.

Recognizing the value of being able to create a plasma for the study of configurations and materials for the re-entry of nosecones and space vehicles, the Plasmadyne Corporation built a device which gives forth a continuous plasma stream, called a plasmajet. Research and development on the plasmajet was funded by the Plasmadyne Corporation.

Although the original application of the plasmajet was in hyperthermal wind tunnels for re-entry studies, many commercial applications have since developed. Above 10,000°F even the most refractory materials are vaporized. By introducing a powdered refractory metal or ceramic into the plasma, one can use the plasmajet to spray a protective coating onto another material, much like the spray of paint. The spraying of refractory materials has found use in the oil refining and chemical industries. For example, protective refractory materials are sprayed on parts of catalytic cracking systems which are subject to destructively high temperatures. Also, relatively inactive materials can be sprayed on piping which is especially subject to corrosion in a chemical processing operation.

Plastics can be sprayed on electronic components by reducing the temperature of the plasma; this protects the components from vibration and moisture. Using a plasmajet to spray plastics eliminates the need for baking. The plasmajet can also be used as a torch to make extremely clean cuts through thick metals; the high temperature of the plasmas makes this possible.

Because of the plasmajet's ability to deliver large amounts of heat per unit time, the plasmajet has been used as a pre-heater in chemical processing. This is also the reason for its use in hyperthermal wind tunnels. The plasmajet has also found commercial use in the welding of difficult materials.

One of the latest applications of the plasmajet is its use as a high intensity light source. The extreme temperature of the plasma provides both brightness and total radiation levels several times that achieved by other man-made controlled sources of light.

Finally, the plasmajet is being investigated as an electric rocket for propelling satellites through space once they have been established in orbit, and for maintaining the attitude of a satellite in space.

Avco Corporation
Research and Advanced Development Division
Industrial Products Subdivision
Lowell, Massachusetts

<u>plasmagun system</u>

The Industrial Products Subdivision was established by Avco approximately two years ago. It is responsible for the further development, testing, and sales of products from the Research and Advanced Development Division which appear to have commercial application. The following is one example.

The development of Avco's plasmagun system began when Avco was required to simulate the aerodynamic conditions of missile re-entry for the Air Force Atlas and Titan missile programs. In order to do this, it was necessary to develop a heat source for high temperature aerodynamic testing. The research conducted to obtain this high temperature heat source resulted in the basis for the plasmagun system. The system itself evolved from further R & D funded by Avco.

The plasmagun system consists of three components: a plasmagun, a power supply, and a control console. Together, these produce a stream of inert gas with temperatures as high as 30,000°F. Powdered materials, injected into the plasma stream, are melted and propelled by the plasma stream, forming a high velocity spray which can be used to coat surfaces.

The plasmagun system provides an economical means of coating many common materials, extending their useful applications, and increasing their durability. In a typical application, a plasmagun spray coating will raise the melting point of the basic surface, increase its abrasion resistance, and produce corrosion and oxidation resistance.

Many of the units are sold to firms in the aerospace industry but customers include a number of firms in industrial product industries.

Metco, Inc.
Westbury, Long Island, New York

<u>plasma flame spray gun</u>

Metco, which has developed a plasma flame spray gun for use in producing flame spray coatings, also produces the refractory, ceramic, and carbide materials for use in the basic gun. Development of the plasma flame spray gun at Metco was not caused directly by the missile/space program, but the missile/space program gave major impetus to this development. Refractory coatings produced by the plasma flame sprays are used extensively as heat barriers in rocket nozzles and other rocket engine parts operating in a corrosive environment.

Present commercial applications of the plasma flame spray gun are in the paper, machine tool, aircraft, small engine, and electronics industries. Wear resistant coatings, conductive coatings, and dielectric coatings are the primary applications in these industries. The company expects future applications in the cryogenic and general machinery fields in both corrosion resistant coatings and wear resistant coatings.

J. TELEMETRY AND COMMUNICATIONS

1. General

An important problem area of the missile/space program is that of establishing absolutely reliable communications with the space vehicle.

The communications system can serve many purposes: telemetering remotely collected data, transferring information to and from astronauts, vehicle tracking and navigation, remote monitoring of the vehicle's condition, and remote control of the vehicle's operation. Radio antennas, transmitters, receivers, and specialized data conversion and handling equipment comprise the system.

Vehicle-borne systems and ground-based systems both contain the components mentioned above, but in quite different form due to differences in allowable weight, size, and power requirements. Vehicle-borne antennas, therefore, are small and transmitters are usually less than 10 watts. Ground-based antennas, on the other hand, are highly directional, movable, and large--having diameters on the order of 100 feet. Transmitters of extremely high power are used. Data to be transmitted are usually coded to make transmission more efficient and reliable.[1]

The total problem of space communications can be subdivided into the following areas: 1) the design of effective antennas; 2) the development of receivers which will amplify weak signals with a minimum of self-induced noise, e.g., parametric amplifiers and masers; 3) emphasis on minimum size, weight, and power consumption in transmitter and receiver development; 4) the application of transmitter and receiver modulation techniques in conjunction with information theory to get maximum reliability in a noise environment; 5) the choice of optimum coding and decoding techniques to prevent accidental or unauthorized operation of remote control functions; and 6) the alleviation of crowding of the electromagnetic spectrum.[1]

Requirements on military communications systems are similar in many respects and equally severe. Therefore, it is impossible to separate the impetus given the field of communications by the missile/space program from that given by the military requirements.[1] Nevertheless, it is believed that missile/space has made a considerable contribution to many phases of the area of communications as typified in the examples which follow this section.

Examples of present or potential commercial communications devices which have received impetus from the missile/space program follow.

Data Control Systems, Inc.
Danbury, Connecticut

improved telemetering equipment

To meet requirements of the Minuteman program, Data Control Systems has improved several of its products. The improvements include advanced circuitry, greater accuracy, increased reliability, extended operating range, miniaturization, the use of solid state components, and plug-in flexibility (one motion changing of filters and tuning units in discriminators). The improved products, all developed with in-house funding, which fall into the general telemetry category are: 1) Voltage controlled oscillators which convert analog voltage signals from transducers into frequency modulated subcarriers suitable for direct magnetic recording or modulation of a radio frequency subcarrier. 2) FM subcarrier discriminators used for data acquisition and playback of tape recorded information or the reduction of signals from FM radio telemetry receivers. The discriminators, available in a wide range of frequencies, convert frequency modulated inputs from tape or receiver to analog voltage suitable for readout and analysis. The discriminators are normally used in conjunction with the oscillator described above. 3) Solid state line driving amplifier capable of summing outputs from up to 18 voltage controlled oscillators. This unit is usually used in conjunction with the voltage controlled oscillator described above. 4) Pulse synchronizer which accepts pulse coded signals of various formats from radio receivers, tape recorders, or other signal sources. It smooths and reconstructs the data bits providing a minimum of three decibel improvements in the signal-to-noise ratio. Pulse synchronizers can be used to improve the quality of input to any type of digital device, e.g., a computer.

The company has conceived and built complete commercial telemetry systems which incorporate the components mentioned above as well as systems experience gained from missile/space research. Commercial applications include: oceanographic research data acquisition and playback systems, medical research data systems, automotive engine test data gathering, aircraft flight testing, impact testing research, and pipeline remote telemetering.

Cubic Corporation
San Diego, California

The Cubic Corporation is primarily engaged in the research, development, and production of highly accurate, complex tracking systems employing both angle measuring equipment and distance measuring equipment (AME and DME). AME compares the phase, at two separate antennas, of signals transmitted from the vehicles to be tracked. The phase difference is proportional to the difference in travel time from a transmitter to the two antennas, and therefore proportional to the difference between the two transmission path lengths involved. Because the separation of the antennas is small compared to the path lengths, the path length difference is directly proportional to the direction cosine (with respect to the antenna baseline) of a vector pointing at the vehicle.

DME consists of a transmitter and interrogator at the measuring station and a transponder in the vehicle. Frequency modulated transmissions are received by the vehicle, re-transmitted by the transponder in the vehicle, and received back and demodulated at the interrogator. The phase difference between the modulated wave and the demodulated wave is directly proportional to the round-trip distance from the interrogator to the vehicle. The actual measuring technique for DME, then, is fundamentally the same as for AME; in each case the desired output is obtained through phase comparison. Cubic DME continuously displays range in feet and in electrical form while Cubic AME presents direction cosine data to six decimal places in both visual and electrical form. These two techniques are basic building blocks in the more complex Cubic systems.

The company, in the early 1950's, received a contract from the Air Force Missile Test Center to produce two missile tracking systems for the Atlas program. Later, Cubic developed a system for Bendix (under NASA contract) to track continuous wave signal sources and provide pointing information for narrow beam width radar. Knowledge gained from these two contracts has contributed to several non-missile/space developments, described below.

MOPTAR

The first, called MOPTAR (Multi-Object Phase Tracking and Ranging), was developed for the National Aviation Facilities Experimental Center to evaluate various landing systems. Since MOPTAR produces considerably more accurate information than the equipment it is used to test, it could also be used for aircraft landing control.

Electrotape

A by-product of Cubic DME techniques is a portable surveying instrument which measures line of sight distances from 250 feet to 50 miles, with resolution to ± 1 centimeter. The system, called Electrotape, consists of two tripod-mounted instruments which are placed at opposite ends of the line segment to be measured. A signal generated by one is received and re-transmitted by the other; the phase shift measured at the original transmitter is used to determine the exact distance.

A South African company called Telurometer had developed a system very similar to Electrotape prior to Electrotape's development. However, Cubic points out that Electrotape was developed independently as a result of its missile tracking DME work and its system is different in several respects.

AERIS

A third system called Airborne Electronic Ranging Instrumentation (AERIS) also evolved from original missile work. AERIS is used in photogrametric mapping, geodetic surveying, and geophysical prospecting.

International Telephone and Telegraph Corporation
ITT Federal Laboratories
Nutley, New Jersey

high-power transmitters

High-powered communications transmitters (power range 10-15 kw; frequency range 2-8 kmc), an outgrowth of 25 years of engineering development of microwave equipment, have been improved for use as ground station transmitters for communicating with satellites and spacecraft. Development was funded partially in-house, partially by NASA for Echo I, and partially by the Signal Corps.

This equipment is currently finding non-missile/space application in long haul point-to-point telecommunication.

parametric amplifier

The company has recently developed a parametric amplifier based on low noise amplification studies and newly available solid state diodes. Development of the amplifier was funded by the company; however, it was built for use in ground station receiving equipment to improve upon the sensitivity of equipment detecting weak signals from space vehicles and weak signals from stars in radio astronomy.

The principle upon which a parametric amplifier works involves an energy storage element which has a variable energy storage parameter. The element is coupled to a resonant circuit, and the energy used to drive the varying parameter of the storage element is transferred to the energy contained in the resonant circuit, and is thereby amplified.

The major advantage of a parametric amplifier is that it amplifies microwave signals with a minimum of self-generated noise. Until recently microwave amplifier operation has depended upon thermally emitted electrons in a vacuum, e.g., klystrons, traveling wave tubes, and high frequency triodes. A significant limitation of the latter types of microwave amplifier is the addition of noise to the amplified signal by the electrons because of their high temperature.

Non-missile/space application of ITT's parametric amplifier is presently in high sensitivity communication receivers applied to point-to-point information transmission.

Goodyear Aircraft Corporation
Akron, Ohio

highly directional antenna (potential) Goodyear Aircraft has produced a series of highly directional antennas which were developed in conjunction with BMEWS (Ballistic Missile Early Warning System), Nike-Zeus, and Syncom programs. One distinguishing characteristic of these antennas is the high pointing accuracy achieved through a minimization of manufacturing tolerances, structural deflections or movement, and electronic variations.

The same technology is now being applied to antennas for commercial communication via space satellites. The results should be improved transmission and reception.

3-D radar (potential) New antenna technology, much of which comes from missile/space research, will permit the development and operation of 3-D radar, of benefit for future space rendezvous. Outside space fields, the technology could be employed for operation, landing, and take-off of Mach 3 aircraft.

Martin Company
Orlando Division
Orlando, Florida

RACEP Martin produces and uses RACEP communications systems. (RACEP stands for Random Access and Correlation for Extended Performance.) The systems are used in tropospheric scatter communication, satellite communication, missile guidance, and ground based mobile telephone systems.

RACEP has its roots in pre-space developments in radar technology, microwave technology, modulation theory, and information theory. The missile/space effort contributed to RACEP's development through requirements for jam resistance and band width efficiency, due to the problem of spectrum crowding, and through developments in advanced propagation techniques, wide-band circuit design, and communication theory. RACEP was originally studied for command and control communications in the Pershing missile system.

RACEP transmits an audio signal by sampling it periodically. The sampling period is broken down into discrete intervals and the amplitude of the audio signal is encoded by assigning a signal of a given amplitude range to a particular interval within the sampling period. The intervals within the period are further broken down into sub-intervals which are each assigned a different frequency. In tropospheric scatter work, where signals bounced off the troposphere are subject to rapid fade (depending on frequency) the use of several frequencies increases the chances that a signal will get through while conserving power. In military or space work, the possible use of several frequencies enhances the ability to code signals. An integrator circuit at the receiver, if attuned to the right frequency at the right time, reconstructs the waveform.

Data transmission takes place in a manner similar to audio transmission. However, in data transmission the interval within a sampling period stands for a binary bit rather than a signal amplitude.

Present commercial applications of the system include mobile radio systems which have the capability of a dial telephone system, but no switchboard, and air-ground communications for air traffic control. Potential non-space uses include commercial over-the-horizon communication links and economical, reliable communications systems for underdeveloped countries.

Philco Corporation
Western Development Laboratories
A Subsidiary of Ford Motor Company
Palo Alto, California

<u>hibernation transmitter</u>

A transmitter developed on their own time by Philco engineers working on the Courier satellite was adopted by the National Geographic Society and used for tracking the hibernation patterns of bears in Alaska. The transmitter was powerful and rugged enough to be fastened to the neck of a bear and used to track the bear wherever it went. While not a very significant transfer, it is an interesting one. The company had no direct connection with the development and has no plans to exploit it due to the limited market.

<u>big dish antennas</u>

Big dish antennas are not new but have been refined as a result of the space program. The major program which gave the antennas the most impetus at Philco was Discoverer. Philco built and refined these antennas for tracking stations all over the world. Once developed, similar antennas were sold to the University of California and the University of Texas for use in radio astronomy.

* * * *

Although there may be some argument as to whether radio astronomy is part of the space program, it is felt that radio astronomy deviates sufficiently from normal concepts of the space program to warrant its inclusion in this report.

Regency Electronics Inc.
Indianapolis, Indiana

<u>telemetering receiver</u>

(potential)

A solid state telemetering receiver was recently built by Regency for the Navy to be used as part of a tracking and scoring system for various shipboard missiles. Since building the original receiver, Regency has uncovered numerous other uses, generally in the missile/space field. The original receiver was funded by the company and built in anticipation of the Navy requirement.

The contribution of this development to commercial purposes is a technological transfer. Regency had been deferring certain high frequency applications in its commercial communications receiver line because of lack of capability. The development of new design techniques and construction capability for the Navy receiver helped to bridge this gap, and projects are underway to adapt this receiver to Regency's commercial line.

Sanders Associates, Inc.
Nashua, New Hampshire

<u>phased array antennas</u>

(potential)

Phased array antennas, still in the development stage for missile/space use, are being simultaneously developed for use in air traffic control. Progress towards both missile/space and commercial uses is actually concurrent, and both have provided impetus for its development.

Potential missile/space uses of this development include multi-target surveillance, tracking, and communications. Air traffic control is seen by the company as its most promising non-missile/space application.

Electro-Voice Inc.
Buchanan, Michigan

<u>improved electro-acoustic products</u>

Electro-Voice is producing improved noise-cancelling microphones, earphones, and high powered loud speakers and projectors as a result of its missile/space work. In these cases, the company improved an existing device, already being sold commercially, to meet the requirements of the program. The equipment is being used in space vehicles, ground support equipment, and in associated communications equipment.

Commercial applications of these products closely parallel the missile/space applications wherever there is a demand for maximum intelligibility and reliability; specific examples include noise-cancelling microphones, widely employed for ground personnel communication around airports, particularly jet airports. Airports are also large users of the company's Compound Diffraction Projector PA loudspeakers where the same problem of overcoming ambient noise is a persistent nuisance.

Douglas Aircraft Company
Diversified Products Department
Santa Monica, California

Two communications systems, which had their origin in the missile/space activities of Douglas, are the Posifix System and the Audio-Pac communications speaker.

<u>Posifix rescue system</u>

The Posifix system, composed of an airborne detection subsystem and a beacon-antenna subsystem, provides an accurate and rapid means of locating distressed persons or objects. In actual use, the Posifix provides straight line homing capability from maximum range.

When the Posifix beacon radiates a signal, a positive directional indication is registered on the indicator in the pilot's panel. In a situation where the pilot can conceivably establish a reciprocal course, i.e., fly away from the beacon, the indicator will begin to give a left or right indication, depending on the deviation from the established course. As the pilot corrects to center the needle, he will receive signals which will call for even more left or right correction as the case may be. Thus he will be brought back on a true course to the beacon. This system has consistently provided positive directional information from 100-mile ranges, with error over target of approximately 20 feet.

The system is being marketed but no units have been sold to date. It is installed in aircraft of the Italian and Spanish Air Forces, and in a U. S. Navy helicopter and a U. S. Air Force plane for testing only.

Audio-Pac communications speaker

The electronic Audio-Pac is an advanced voice amplification unit for protective breathing equipment. After initial design by Douglas personnel, it was developed in cooperation with municipal and industrial experts in protective breathing equipment.

The device is wireless, measures 2-1/2 inches in diameter, and weighs about 11 ounces with batteries. It can operate continuously for 8 hours, has a maximum range of 500 feet, and performs efficiently within a temperature span of 160 degrees. It has recently been placed on the commercial market.

2. The Maser

Both General Precision, Inc. and General Telephone and Electronics consider the maser a device which has received a considerable amount of missile/space motivated development; several persons at other companies concurred but were less definite in their opinion. However, no one interviewed was close enough to the situation to cite a specific example of missile/space transfer to the maser. Since the maser is an important development which appears to have a partial missile/space connection, and would be conspicuous by its absence, a brief background is presented here.

The maser (an acronym for microwave amplification by stimulated emission of radiation) is important to space communication because of its ability to amplify a weak signal with a minimum of self-generated noise. Furthermore, the maser may open vast new areas of the electromagnetic spectrum for communication in the near future.

The maser works by elevating electrons in a particular element or compound to an unnaturally high energy level. When the electrons are made to fall back to their normal energy level, coherent, monochromatic electromagnetic energy is emitted.

The maser: 1) is the only device which emits coherent radiation in the infrared and visible portions of the electromagnetic spectrum, 2) can be made into the most noise-free microwave amplifier known, 3) is the most monochromatic infrared source known, 4) has extreme frequency stability, 5) has an extremely high output power radiation intensity which can be focused to 100 million watts per square centimeter, and 6) has a very narrow beam of output radiation.

These unique properties give rise to proposed applications in space and terrestrial communications, more accurate radar, metal or material cutting and welding, weaponry, time measurement, chemical processing, and basic research.

The first stimulated emission was noted in lithium flouride at 10 megacycles by Purcell and Pound in 1951.[2] This system had no power gain, but in 1953 J. Weber proposed that an amplifier could be built.[3] The first two-level gas maser was proposed and built by J. P. Gordon, H. J. Zeigler, and C. H. Townes in 1954-1955.[4] The first three-level solid state maser was proposed by Bloembergen in 1956,[5] and the first three-level solid state maser was built by Scovil, Feher, and Seidel in 1957.[6] All of the preceding masers operated in the microwave region. The first optical maser (laser) was built at Hughes Aircraft Company by T. H. Maiman in August 1960, using a ruby crystal which gives a red light output. R. J. Collins and others at Bell Laboratories announced their own optical maser in October 1960, also made from a ruby crystal. P. P. Sorokin and M. J. Stevenson at IBM announced a calcium flouride optical maser in January of 1961, and P. Miles at MIT was reported to have constructed a barium flouride optical maser in May 1961.[7]

K. VIBRATIONAL TESTING

In recent years there has been an intensified demand for reliability as a design consideration, especially in the missile/space and aircraft industries. As a result, many ground-based equipments have been designed to simulate the environment in which components must function reliably. Accelerations due to shock and vibration and vice versa are among the most important of the many environments that must be considered in the design of equipment.

During World War II various aircraft components and systems failed to operate properly due to the effects of vibration; this led to vibrational testing of aircraft components. The first type of "shaker" used for this purpose was a table designed to oscillate in one plane at frequencies up to 50 cps. The table was driven by an electric motor through a variable speed drive and a crank or a "Scotch Yoke." About 1946 more refined studies of vibration in aircraft led to vibration environmental test specifications requiring sinusoidal vibration tests ranging in frequency from 50 to 500 cps. Since mechanically driven shakers were inadequate, electrodynamic vibration exciters were developed to meet these requirements. Later, when jet and rocket engines came into wide use, it was found that vibrations measured on jet aircraft and missiles were seldom sinusoidal; vibrational energy was found to exist over a wide frequency range.

The electrodynamic exciters mentioned above were subsequently adapted to provide a random vibrational environment in which signals ranging from 20 to 2,000 cps could be superimposed on the controls of the vibration exciter.[1] Devices for producing various types of shock pulses on aircraft and missile components have also been developed to improve component reliability. A mechanical shock is characterized by significant changes in stress, position, acceleration, or velocity in relatively short periods of time. The schemes used for analysis of shock motions may employ either a pulse of known waveform or a complex shock whose waveform cannot be expressed in simple mathematical form. Equipment designed to produce and evaluate the effects of this type of motion range from simple drop test rigs to the fairly complex systems discussed in the examples which follow.

Vibration and shock testing today is an indispensable tool of engineering development, particularly in the aircraft and electronic industries, as well as in the missile/space field. It promises to become increasingly important in the future. The more severe vibration environment encountered in supersonic aircraft and missile/space operations requires continual development of new and improved techniques and equipment for vibration and shock testing.[2]

Avco Corporation
Research and Advanced Development Division
Industrial Products Subdivision
Lowell, Massachusetts

<u>shock test machines</u>

A series of shock test machines which Avco is currently producing had its origin in the Air Force's Titan missile program. At that time, Avco developed the machines to shock test missile assemblies, verifying their reliability prior to production runs.

The SM-030 tests large assemblies which must operate with a high degree of reliability. This machine has a capacity of 1,000 pounds with standard impact devices, and it subjects large specimens to a wide variety of shock pulses including half-sine and sawtooth.

The SM-005-2 is designed to test electronic and electromechanical components in production operations. It will produce and precisely reproduce those shock pulses required for relay, tube, transistor, diode, resistor, and micromodular package qualification including the 3,000g, 0.2ms pulse required by MIL-S-19500B and the 30g, 11ms pulse required by MIL-STD-810. This machine has a capacity of 30 pounds; in operation the specimen carriage is raised and propelled downward by pneumatic pressure. It has been designed to operate from standard plant air lines and pressures.

The SM-010-3 machine is a precision free-fall shock test device which accurately produces the shock pulses required by most missile and electronic environmental test specifications. Having a specimen weight capacity up to 100 pounds, it is being used to qualify gyros, relays, transistors, tubes, diodes, accelerometers, and many electrical, electronic, and mechanical items that must operate with a high degree of reliability.

The company anticipates that this series of shock test machines can contribute to substantial savings for industry by eliminating, prior to large production runs, those designs which would be faulty or marginal.

The majority of sales to date have been to firms having missile/space applications. In addition, however, a number of units have been sold to the aircraft industry to simulate and check landing shocks for commercial aircraft production.

<u>multi-purpose environmental test fixture</u>

Also originating in ballistic missile research and development conducted by Avco, this testing fixture is a modified T-type with horizontal and vertical mounting surfaces. It is cast magnesium with exceptional resonant response that is well suited to environmental testing applications. Transmissibility does not exceed 1.10 up to 2,000 cps.

With both a vertical and horizontal mounting surface, specimens up to 25 pounds can be subjected to test conditions along all three mutually perpendicular axes in the single fixture. To meet the requirements of more demanding test programs, the device is available in beryllium at extra cost.

The fixture may be used interchangeably for vibration excitation, shock, acceleration, and other applications that require a rigid, resonance-free mounting for the test specimen.

The majority of sales to date have been to the missile/space industry. However, some sales are now being made for use in aircraft production.

Both the shock test machines and the multi-purpose environmental test fixture required company funded development to adapt them to the commercial market.

Ling-Temco-Vought, Inc.
Ling Electronics Division
Anaheim, California

<u>vibration</u>
<u>test</u>
<u>equipment</u>

The Ling Electronics Division manufactures, among other products, vibration testing systems for both industry and the military. The equipment is used for the purpose of simulating dynamic vibratory conditions in the laboratory or on the production line which may be encountered in the actual end use of the article being tested. In the laboratory, the equipment is used for fatigue testing of materials, components, and packages to specified levels of acceleration and vibrational frequency. On the production line, it is used to test components to assure their performance within the specified vibration limits.

The principal present use of these systems is for testing the reliability of missile/space vehicles and their sub-components. Prior to its use on missile/space systems, the equipment was used in the aircraft industry for testing both propeller and jet-driven planes.

Commercially, this equipment has been applied to automotive research for improving performance of automobiles when subjected to vibration. It was made commercially feasible for use by the automotive industry by the relatively large scale production of similar systems for the missile/space market. This latter development was funded by the company.

Textron Electronics, Inc.
MB Electronics Division
New Haven, Connecticut

<u>vibration</u>
<u>test</u>
<u>equipment</u>

The MB Electronics Division develops and produces sophisticated machines which simulate advanced environmental vibrations existing in military aircraft, ballistic missiles, and satellites. The purpose of the machines is to improve the reliability of space and military equipment. Sales of the equipment, developed with company funds, are primarily to firms engaged in the development of space and military vehicles.

Some of these machines are now being used to improve the reliability of commercial items. In addition, less complex machines are being developed for less demanding commercial applications. The company anticipates that its activities in these commercial areas will increase in the future.

L. PACKAGING AND SHIPPING

Circumstances which are particularly acute in the missile/space industry have necessitated improvements in packaging and shipping containers. Components developed for the industry usually have a high value per pound and are easily damaged. In addition, by the time they reach their destination where they become part of a missile, rocket, space vehicle, or support equipment, most components have been handled many times by subcontractors as well as the prime contractor. Two problems are thereby created: 1) The probability of damage is increased due to frequent handling. 2) Constant packing and unpacking of parts or sub-assemblies for inspection and shipment significantly increases the overall cost.

Devices which have been developed to alleviate these problems are described below.

Navan Products, Inc.
Subsidiary of North American Aviation, Inc.
El Segundo, California

<u>Klimp and Kudl-Pak</u>

Navan Products, Inc. has developed two devices in the course of its missile/space work which now have application to other industries. The first of these products is called a "Klimp." A Klimp fastener is an L-shaped spring wire clamp which replaces a nail in holding a packing box together. Although it is initially more expensive than a nail, it is far cheaper to use in the long run, according to Navan. Neither the Klimp fasteners nor the packing box are damaged in the packing or unpacking operation, which means that packaging material can be used repeatedly. The unpacking operation is accelerated due to the fasteners' ease of removal. Other advantages of Klimp fasteners include: disassembled panels can be stored in one-fifth the space required to store assembled boxes; box panels are being standardized and can be mass produced; and modular panel construction is possible, permitting a wide variety of boxes to be made from a relatively few basic panel sizes.

Klimp fasteners are now being marketed to many different industries. Large users of Klimp fasteners include firms in the automotive, furniture moving, rubber, produce, and food industries. The U. S. General Services Administration has made Klimp fasteners a stock catalog item.

In the process of marketing the Klimp fastener, Navan had to sell military and industrial packaging interests on creating new wooden container specifications. For example, the existing cleated container specification set forth 13 different cleat sizes. This presented a need for an impractical number of Klimp sizes. Navan got specifications written and published which set forth 3 cleat sizes. This effort alone took from 1957 to 1961. The National Wooden Box Association is now sponsoring a federal commercial specification for Klimp fasteners paralleling the military one.

A variation of the standard fastener is called the "Klimp Celery Clamp." This is in the final stages of approval for sale to the food industry to hold vegetable packing boxes together and to prevent much in-shipment damage resulting from load shifting.

The second packaging product, marketed by Navan, is called "Kudl-Pak." Kudl-Pak containers are made from a rugged, vacuum formed or injection molded plastic case which is hinged on one side and snaps together on the other. The inside is filled with a polyurethane flexible cushion, making surfaces of the cushion overlock when the box is closed and holding the contents securely in place. The flexible cushion adapts itself to the shape of the part. The distinguishing advantage, therefore, is a standard type of package which adapts itself to any shape. The need for custom nesting is eliminated.

Kudl-Pak containers are now being sold in volume to producers of electronic products, precision controls, precision machined parts, and timing devices; use in many other industries is rapidly increasing. An interesting side light to the marketing of Kudl-Pak containers is the way in which Navan dramatizes their advantages. Salesmen place a raw egg inside a Kudl-Pak box and air mail it to prospective customers.

Although Navan had no expectation that Kudl-Pak containers would replace egg cartons, a firm is now contemplating their purchase for this purpose. This firm wants to ship very expensive, "100 percent disease-free" eggs to laboratories in Kudl-Pak boxes.

General Dynamics Corporation
General Dynamics/Electronics
San Diego, California

Shock Master(R) The Shock Master is a low-cost mechanical device that positively indicates with a bright red signal when predetermined shock levels have been exceeded. It can be installed in containers, boxes or crates, or on cargo or vehicles, providing the shipper, the manufacturer, and the customer with an irrefutable record of shock.

The device was developed by the Pamona Division of General Dynamics/Electronics, under a Navy Bureau of Ordnance contract, as a shipping container for the Terrier missile. It automatically reports rough handling and thus eliminates undetected and potentially damaging shocks to sensitive instruments during transit.

The device is mounted inside the container before it is sealed for shipping and operates in the following manner: The instrument contains a spring-loaded weight with an integral trigger which engages with a spring-loaded sleeve. When tripped, the sleeve moves along a guide rod and exposes a red band. The instrument is incased in a metal housing covered by a transparent plastic dome. When shock occurs, the weight is forced down against the spring, disengaging the trigger from the sleeve which moves to expose the red band. The device can be reset by inserting a wire into a hole on the side of the dome and pushing the sleeve back to its cocked position. Characteristics of the device include:

Accuracy: the standard model trips with ± 10 percent of setting. Closer tolerances are available.

Tamper-proof: access to reset can be protected by a safety wire and inspector's seal.

Size: the standard model measures 1-1/2 inches in diameter and 1-1/2 inches high. Smaller devices are available.

Multi-plane response: the device is sensitive to axial shock in one direction and to radial shock in all directions.

Various models are now available commercially with shock readings from 5 to 50 G's. The Shock Master can also be used for the evaluation of container design, packaging techniques, carrier performance, and handling methods. In addition to being used quite extensively for the shipment of rocket and missile components, General Dynamics reports that approximately 5,000 Shock Masters per year are now used by the private sector of the nation's economy.

M. MANAGEMENT AND CONTROL--PERT

The missile/space program has had its effect on management and control, the most publicized example being PERT (Program Evaluation and Review Technique). PERT is an outgrowth of the sheer complexity of the Navy's Fleet Ballistic Missile, or Polaris, program.

In 1956, a Special Projects Office (SPO) was organized by the Department of the Navy to manage the Polaris program. Numerous management tools, some old, some newly developed, were used by SPO. For example, a "Management Center" was established to keep anyone concerned with the program up to date on progress relative to plans: a single page format, called "Program Management Plan," was used to show milestones, schedules, task responsibility, supporting responsibility, monitoring responsibility, and progress; variations of Gantt charts were used to depict schedules and progress; and line of balance charts were used to analyze the mix of effort going into the production of a particular item. [1]

However, despite the merits of these procedures, additional information was needed to assess the validity of plans and schedules, to measure R & D progress where the standard measure--money spent--did not necessarily correlate with progress, and to predict the probability of meeting objectives. In February 1958, a team was organized by SPO to produce a system to do these things. The team consisted of personnel from SPO, consultants from Booz, Allen and Hamilton, and specialists from the Missiles and Space Division of Lockheed. Willard Fazar, credited with guiding PERT's development, was team manager. Due to the urgent nature of the Polaris program, and the particular importance of time in the missile/space industry, it was decided to use time as a common denominator. A significant change in resources or technology always means a significant change in time, and in the defense industry cost is often less important than time and may be dependent on time. [1]

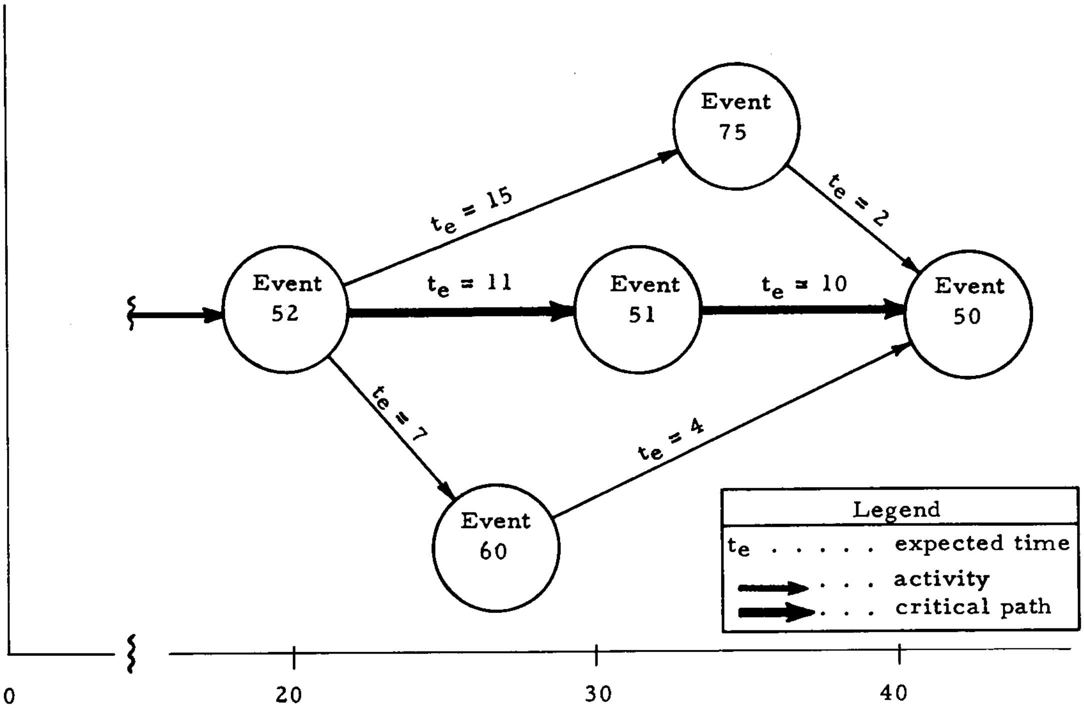
PERT, then, is developed around a time sequence flow diagram. Milestones, representing important events in the life of the project, are selected and linked graphically with arrows to portray interdependencies. Actual work activity is represented by the arrows joining the milestones; the resulting flow diagram, structured around these important events, is called the PERT network.

Times necessary to complete each task between events are estimated in such a way as to give an appropriate measure of uncertainty. The "most likely time," "optimistic time," and "pessimistic time," are obtained from the person who is to complete a particular activity or task. A weighted average or expected time is calculated, giving the time for which there is a 50 percent chance of completing the activity.

The simplified diagram presented below (Figure 1) shows a segment of the PERT network including the "critical path"--that series of interrelated tasks which will take the longest time for completion, and therefore, that chain of events which determines the minimum completion time for the total project. When the network is complex, as it was in the Polaris program, a digital computer is used to determine the critical path, to set the date for the end objective, to calculate the latest date by which each event must be finished if the project is to be completed on time, and to calculate the uncertainty involved in reaching each milestone.

Figure 1

SEGMENT OF A PERT NETWORK



As is often the case in the invention process, a similar scheduling technique was being developed at approximately the same time as PERT, but quite independently. In the Engineering Department of E. I. du Pont de Nemours and Company, a group was formed in early 1956 to study the application of management science to the management of engineering.[2] A first area of attack was the planning and scheduling of construction and engineering design; the group felt that much could be gained by combining all planning and scheduling information into a single master plan. In January 1957, Morgan Walker of the du Pont group approached Dr. John W. Mauchly and James E. Kelley, Jr., of the Univac Applications Center of Remington Rand Univac for assistance. Much work led to the formulation of a model, MCX (Minimum Cost Expediting)--a parametric linear program that has as its objectives the determination of the minimum cost of a project as a function of its duration. In July 1957, the theory was tested on a hypothetical construction project, and the method was shown to hold great promise. Nearly all the rules for flow diagramming the project were developed at this time. MCX became an adjunct to a broader system which was to be called CPM for Critical Path Method. (The critical path was, at that time, called the "main chain," the word "critical path" being borrowed later from the developers of PERT.)

The construction of a new $10,000 chemical plant facility was selected for the first live test. By March of 1958, the first part of the test was complete. The results indicated that two months could be gained at no additional cost over the time and cost as estimated by conventional means. Crashing the project, using MCX, would gain an additional two months at an additional cost of only one percent.

The developers of CPM were not aware of the PERT development efforts until early 1959, when a reporter from Business Week informed them of this parallel effort. As of 1959, there were many basic differences between PERT and CPM. Now, according to James E. Kelley, Jr., who is given much of the credit for the development of CPM, the techniques are similar and becoming more alike all the time. After the original development of PERT and CPM, many similar techniques were developed, each with its own minor variations and name. For example, the Air Force used the system as PEP, but has since returned to the code name PERT.

What are the original differences in CPM and PERT? First, PERT is a system which evaluates existing schedules while CPM generates plans and schedules. The reason for this is probably that when PERT was developed the contracts for the Polaris had been let, and the contracted schedule for most of the work was known. However, the magnitude of the effort was great (there were over 3,000 contractors and agencies involved), and a tool was needed to evaluate the schedule and to indicate bottlenecks in advance. Another important difference between PERT and CPM is that with PERT job durations are random variables--probabilities are assigned to the length of activities--whereas job durations are known fairly precisely with CPM. Therefore, one time estimate is made with CPM compared to PERT's three time estimates. PERT, as originally used, did not include cost as part of the model while CPM did. Now, the Navy's SPO has developed a new system called PERT/Cost which does take cost into account.

Another important difference is that PERT generates one set of schedule limits while CPM can generate a spectrum of schedules with the minimum cost for each. A final difference is in the approach in constructing the model. PERT, as was noted, is constructed by selecting important milestones in the progress of a project and scheduling around these while CPM is constructed around the jobs or activities that make up the total project. It can be seen, then, that PERT is most useful for large, complex operations where the individual tasks are being done on a first time basis or are of a research nature where a great deal of uncertainty is involved which needs to be taken into account. CPM, on the other hand, deals with projects where the time for completion of each task can be estimated fairly accurately in advance, and the planner wants a series of schedules for the task with the cost for each. Quite naturally, PERT is more suited to the missile/space industry, defense industry, and research, while CPM is more suited to civilian construction and maintenance.

Why then is PERT included in this report as an example of contribution of missile/space spending? First, specific references were found to the commercial use of PERT (several other rather vague references were also found, but it was not possible to determine whether PERT, CPM or a hybrid was used). For example, PERT was used to keep track of the production of the Broadway play "Morgana."[3] At the Southwest Research Institute, a hybrid, simplified PERT/CPM was used to help schedule construction of a $20,000 shock tube.[4] H. Sheldon Phelps refers to the use of PERT in the construction of an office building, a bakery, plant and facilities move, new product design, development and production, changeover from pilot plant to full production, and computer installation.[5] (The reader is cautioned however that CPM is often called PERT, and vice versa in the literature; some of these applications could be hybrid PERT/CPM.)

Second, and probably most important, the existence of PERT, its use by government contractors, its spectacular success on the Polaris program (it was credited with saving two years over original estimates), and the publicity received therefrom, has significantly accelerated the diffusion of PERT and CPM throughout industry. The American Management Association, Management Systems Corporation, the Service

Bureau Corporation, Mauchly Associates, and several other organizations offer cram courses in PERT, CPM, or both.

Finally, CPM and PERT are really a way of thinking rather than specific, well defined techniques.[6] Once one is familiar with PERT or CPM through reading, a class, or introduction on a government contract, he can evaluate other scheduling problems in the terms of flow network and critical path, and other techniques are easily assimilated. Here, then, is another way the missile-developed PERT can, and probably has, lent impetus to the industrial use of critical path techniques in general. The General Electric Company, for instance, introduced to PERT on the Polaris program, has adopted either PERT or CPM in all its divisions.[7]

Chapter VII

DIFFUSION OF TECHNOLOGICAL INFORMATION

The data in Chapter II, reporting the results of the inquiry into information flow contributing to technological transfers, are rather inconclusive because of the limited number of replies and the varying sources of the replies. However, the reply tabulation does support some of the indications and results from other research on the diffusion of technological information. The combination of the results of this study and those of other research do point out some of the specific questions which need to be answered if the transfer of missile/space technology into commercial applications is to be planned and optimized.

A. BACKGROUND: THE FLOW OF TECHNOLOGICAL INFORMATION

The simplest element of communication may be considered the communication link, a relationship between an information-disseminating source and an information-consuming receiver. The two are related by some sort of channel of communication. For example, an airport runway marker light is related to the pilot of an approaching aircraft by a visual communication channel. One person speaking to another, over some distance, may depend on a telephone circuit for his channel of communication.

Two people conversing face-to-face, or by telephone, or by constant exchange of mail, make up a two-way link. This is still a fairly simple process; the source has some acquaintance with the receiver and the receiver's information requirements. A direct feedback channel is available for modifications leading to better understanding.

The process of communication between a single source and many receivers is more complex. It reaches another level of complexity when many of the receivers are unknown to the source and the disseminator is uncertain about the receivers' requirements. Feedback is thus less reliable. The ability of the source or disseminator to influence the communication effects becomes subordinate to environmental and internal factors directly affecting the receivers.[1]

Finally, most complex and apparently most applicable to the flow of space science and applied science or technology into commercial applications, is the situation with a great many disseminating sources and a great many consuming receivers. Information must pass through numerous links and feedback must return through numerous links. Receivers' information requirements and motivations may be quite unknown to sources. Conversely, the receivers may be uncertain about credibility of sources.[2]

A direct communication link, controlled by a disseminating source and a consuming receiver, is not often apt to connect a creator of new scientific information and a user or adopter of missile/space technology in non-missile/space applications. Instead, information about the technology is usually diffused through a network of many different channels, many different receptions and redisseminations, and among many sources and receivers.

The flow, where that term applies, is apt to be a many-step flow.[3] Furthermore, different types of information may be required in different stages of the process of adopting an innovation for use. One source defines these stages as: 1) awareness, 2) interest, 3) evaluation, 4) trial, and 5) adoption.[4]

B. APPLICABLE RESEARCH

Certain research on the diffusion of technological information seems particularly appropriate to speculation about the flow of missile/space technology. The resources devoted to research by the U. S. Department of Agriculture and the land grant colleges have led to many studies on diffusion of innovations among farmers, along with study of adoption by farmers of technically advanced farming practices, e.g., a hybrid seed corn.[5] The number of such studies is given as at least 286 by Rogers.[6] A different field of inquiry, perhaps slightly more comparable to the commercial application of missile/space technology, includes a study of how doctors in four communities responded to an innovation in medical service, a new antibiotic.[7] In the examples, study generally was of 1) the movement of a specific innovation, 2) over time, 3) through identified channels of communication, 4) in a social structure--described in varying detail in the different studies.[8]

None of these studies was primarily concerned with motivations for communication activity or with varying information requirements among different people applying the technology. However, the authors of the corn study inferred from their data that interpersonal influences affected the patterns of diffusion of the innovation. The drug study went further and indicated that interpersonal influence (among doctors) led to earlier adoption of the innovation by those doctors who were more personally integrated with others in their medical community.[8]

A study possibly applicable to some problems of communicating missile/space technology to commercial applications people is reported in The Flow of Information Among Scientists.[9] University scientists were interviewed about their scientific information needs, their means of exchanging information, and the conditions influencing their information needs, opportunities, habits, and satisfactions. Numerous motivations for communications activity were identified: 1) the reference function, finding answers to specific questions; 2) keeping abreast of current developments in one's field; and 3) other functions, e.g., brushing up on a forgotten field or a new field, judging the significance of a topic, broadening one's areas of interest, and getting reactions or feedback on ideas. From this the authors conceive of scientific communication as a complex system: "...the totality of publications, facilities, occasions, institutional arrangements, and customs which affect the direct or indirect transmission of scientific messages among scientists."

One useful concept applied in the study is categorization of communication forms and channels as 1) formal or planned, such as technical journals, abstracts, review volumes, monographs, newsletters, technical meetings, and conferences; and 2) informal, personal, or accidental channels, such as material found in literature while searching for another topic, information contributed by fellow scientists upon being informed of colleagues' current work or in answer to a specific question, correspondence with colleagues, or corridor conversation at conferences or meetings.

Several efforts were made to measure the relative value to the scientists of these two classes of communication. Generally, scientists' choices appeared to be about evenly divided between the formal and informal categories, although different scientific disciplines had quite different patterns of channel preference.

This study by Glock, et al., is labeled as a pilot study. It reports on interviews with 77 scientists in three disciplines in a single university. Its results are modestly described by the authors as "...illustrations of the possible outcome of further work and not as reliable findings." Nonetheless, it appears to be an extremely valuable source of insight into communication of scientific information.[10]

C. OBSERVATIONS ON THE APPLICABLE RESEARCH

The applicability of these studies about the communication of technology and scientific information to our study of missile/space technology flows is uncertain. However, some observations on similarity and on difference may be hazarded.

1. The farmer adopting a new farming technique, the doctor using a new drug, and the scientist reading about the modification of a theory are all primary users of certain types of technological information, and they are identifiable as potential decision-makers concerning the application of new technology. It is taken for granted that new farm technology will be primarily applied in farming, that medical innovations will be first used in the practice of medicine, and that scientific information will be applied to further scientific research. The communications systems serving these groups have evolved to diffuse technological information through a specific social structure or community.

By contrast, this report concerns the flow of missile/space technology from its sources (or within the source organization) to firms which apply this technology to non-missile/space uses. These "by-product" uses are secondary uses. The primary uses of missile/space technology are, of course, application to missile/space programs.

The flow of technological information to secondary users may be more complex than it is to primary users. The secondary users and related decision-makers may be a less easily identified audience. They may have no connection with the missile/space industry and thus they may be in separate industrial social systems or communities. Conversely, they may be in missile/space firms. The diffusion of missile/space technology to secondary users may be substantially slower and less complete than is the diffusion process serving primary users, and the degree of similarity of use may affect the diffusion rate.

On the other hand, the secondary user may be in the same firm or the same research group with a primary user or originator. If a product is directly transferred and marketed, the secondary user of technology may be the same person as the primary user. The unit of information leading to a transfer is often information about the characteristics of a missile/space or primary application, rather than detailed information about the technology involved in the primary application.

2. Since the secondary or transfer user of missile/space technology is applying this information for other than originally-intended purposes, he evidently had access to information on other uses, actual or potential. This indicates that the application of missile/space technology to marketable commercial uses requires information inputs on market requirements and market potential, as well as information on the technology being adopted. Navan Products, Inc., a subsidiary of North American Aviation, Inc., is an organization set up to acquire and analyze such data, and thus facilitate by-product development. (See Chapter VIII, "Company Organization and By-Product Exploitation.")

3. The Flow of Information Among Scientists roughly classified scientific communications systems as formal and informal.[9] The two classifications cover the channels of people doing generally basic research in a university environment.

The commercial application of missile/space technology is apt to take place in an industrial community which may be quite different. For instance, scientific and/or applications information consumers in a firm may acquire technology informally from customers, through sales contacts, or more formally from customer requirements information such as MIL Specifications (an example of this latter case being the Amphenol-Borg connector described in Chapter VI). The firm's contacts with other salesmen offer additional informal channels, and suppliers' catalogs, advertisements, or meetings furnish more formal channels. Such marketplace channels were not mentioned in the university study.

Motivation may differ in the two environments. The university scientist is often thought of as seeking knowledge for its own sake; the commercial applications decision-maker or firm is largely motivated by desires for profit, market preemption, continuity of the firm, and/or other commercial goals. The industry scientist or engineer may have combinations of these motives.

The university scientists studied were working under a long tradition of free interchange of information and technology; missile/space technology is sometimes inhibited from free communication by its common identity with defense technology which is often highly restricted by security agencies. The diffusion process of missile/space technology, at the application level, may also be inhibited by proprietary restrictions imposed by firms planning either missile/space or non-missile/space applications. (Several firms preferred not to participate fully in this study because of such proprietary restrictions.) Finally, the quantity and the increased rate of output of scientific information have overloaded some of the existing communications systems.[11]

4. Thus, it appears that a third type of communications system or facility has been established to handle space and defense scientific information and technology, in addition to the earlier defined formal and informal systems. The third type is made up of many special channels, disseminating agencies, documentation agencies and--in at least one case--a facility combining the functions of acquisition, storage, and retrieval, selective dissemination ("to those who need to know"), and evaluation of how much information is needed for certain missions as yet unknown. (See description of the Atlas Project at the end of this section.)

These special systems are usually set up to cope with special problems, or to act as supplements to the normal diffusion process. The variety in the special systems is as great as the variety in the problems. Some of these problems result from security restrictions, blocking the normal flow of data. Some firms may hesitate to publish research results until they are sure they can benefit from their own research, such as reasonable expectation that patent protection will be granted. Many firms and individuals with little experience in either generating or applying advanced technology now wish to do so but are uncertain where they can acquire information. Some advanced applications of science require information from several disciplines. Scientists and engineers, particularly in industry, may find it difficult to identify and communicate with other scientists and engineers in other firms working on similar problems or holding similar interests. Research sponsors may have difficulty identifying the right man for a particular project, and it may be hard to identify the right man for informal contact. Finally, the rapid growth in certain areas of research has combined with institutional efforts to increase the quantity of scholarly and scientific publications and to multiply the publications, abstracts, and research reports that are available. It is difficult, even for the government, to keep track of what government-sponsored research is going on. The importance and magnitude of some of these problems is the subject of a study recently reported by a panel of the President's Science Advisory Committee.[12]

Solutions for many of these problems have been attempted by creation of special communications systems or devices such as:

Armed Forces Technical Information Agency (ASTIA) (now the Defense Document Center)

Office of Technical Services

Scientific and Technical Information Facility of the NASA Office of Scientific and Technical Information

Defense Metals Information Center

Vela Seismics Information and Analysis Center at the University of Michigan

Smithsonian Science Information Exchange

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Baldwin-Lima-Hamilton Company's Western Regional Strain Gage Committee and Annual Seminar

Special Committee on Brittle Fracture of High Strength Materials of the American Society for Testing Materials

Current ARDC Technical Efforts (CATE) System (now ASTIA DD-613 program)

Atlas Project of the Lovelace Foundation for Medical Education and Research

Applied Space Technology Regional Achievement Project of Midwest Research Institute

These special communications systems were noted during field work on this project, but represent only a small and rather random selection from a vast number of facilities. The Office of Aerospace Research, USAF, in 1961 compiled a listing of 886 centers, services, sources, and systems engaged in collecting, storing, and disseminating scientific data and information applicable to aerospace research.[13] Specialized Science Information Services in the United States, compiled by the National Science Foundation in 1961 is another reference document on sources of information.[14]

Five of the first six special systems listed above are substantially concerned with storage and dissemination, and all are rather well known and are described in the OAR and NSF catalogs. Detailed information can be obtained from the agencies themselves. The remainder are examples of special systems established to cope with specific technological communications or information problems, and are briefly described below:

The Western Regional Strain Gage Committee sponsors semi-annual seminars on applications and requirements for and capabilities of resistance-type strain gages. The Committee is sponsored by Baldwin-Lima-Hamilton Company, a leading manufacturer of this type of instrumentation.

The Special Committee on Brittle Fracture of High Strength Materials of the American Society for Testing Materials was established at the request of the Department of Defense. The Committee includes representatives of industry, government laboratories, Department of Defense and the ASTM, and it determines standard test methods and design specifications.

The Current ARDC Technical Effort (CATE) program was a mechanized system for quickly identifying the individuals working in particular technical fields of interest to the Air Force. It has now been taken over by ASTIA as a part of that agency's DD-613 program and information from it is available only through the Department of Defense.

The Atlas Project at the Lovelace Foundation for Medical Education and Research is seeking to mechanize the acquisition, storage and retrieval, selective dissemination to those who need to know, and evaluation of information on bio-astronautics. The evaluation function includes quantitative estimates of the proportion of research yet to be done in specific fields before certain space missions can be attempted. Monthly atlases or state-of-the-art reviews are to be furnished NASA on certain critical areas of bio-astronautics research.

The Applied Space Technology Regional Achievement Project at Midwest Research Institute is experimenting in the field with ways to speed up the transfer of space related technical developments to industry. The Institute screens, repackages, and disseminates information on new technology to several hundred firms in the Midwest. This project is sponsored by NASA.

D. TOPICS FOR RESEARCH

In Chapter II it was suggested that optimization of the commercial application process (of missile/space technology) would depend on greater understanding of the technological diffusion process than now exists. It was also suggested that the nature of the different types of information needed by technology users and by-product developers should be identified and defined. Specific questions for such research are asked in the following paragraphs.

Several questions for further research asked in The Flow of Information Among Scientists are probably appropriate for consideration here, too.[15] Assuming the importance of informal or personal communication channels in the flow of missile/space technology, what are the forms of personal communication which bring relevant news to its users? How much access do scientists (or other consumers of scientific information and technology) in different positions have to the fruitful forms of personal communications? Should more research be made available through literature and formal channels, or should informal channels be made more usable, or both? (The informal channels might be made more usable by registers of personnel, indexed by field of interest or current effort similar to the Smithsonian Science Information Exchange, or the CATE system described in Section C.) How is an individual motivated to keep himself informed?

These lead to other questions. How important are the informal or personal channels for information in the industrial environment? What are the intra-firm information diffusion processes? How does the industrial environment for consumers of scientific information differ from the university environment, and which of these differences affect the flow of scientific information and technology? Are there differences in social structure or institutional environment between missile/space facilities and non-missile/space commercial facilities which affect the flow of scientific information between the two? More specifically, what channels are most easily used in common by both missile/space and non-missile/space (or commercial) consumers of the information? Does information flow more easily from non-space research to space application than from space research to non-space application?[16]

The formal systems of scientific communication and the often-related special systems are certainly of great importance in the information diffusion process. The entire field of documentation, machine retrieval, machine translation, and machine abstraction is presently the subject of intense research efforts,[17] and a review of this would probably dominate any discussion of the formal and special systems. Such a review is beyond the scope of this study, although it might evolve if these suggestions for further research were followed.

Another basic concern is the possible difference between primary use of missile/space technology (its use in missile/space programs) and secondary or by-product use. Do the information-consuming habits of the primary and secondary users differ? If this should be a fruitful approach to research, a number of questions to users might concern differences in channels, information needs, appropriate level of abstraction (statement of principle vs. detail of operation or production), and motivations or incentives to adopt missile/space technology for other uses.

In the specific field of commercial applications of missile/space technology, several questions seem appropriate. What sorts of information on the results of space R & D most often lead to commercial applications? That is, where along this continuum does the information fall which has led to secondary applications?

pure scientific information — description of a primary application

How does this information get to the decision-maker (individual or collective) who decides on the development and marketing of commercial products? Who is this decision-maker? What are his motivations for commercial application of missile/space technology? Who are the other consumers of scientific information and technology involved in development and what are their motivations? To what extent do all of these individuals consider commercial application of missile/space technology to be in the national interest? In the interest of their firm? In their personal interest? What is the role of change agents, i.e., special advocates of the application of missile/space technology to commercial uses, in accelerating the transfer of missile/space technology?

The other area of information flow research which is suggested by the field work for this project and by the questionnaire response concerns requirements information. That is, what information on market requirements (actual or potential) is necessary for commercial application of missile/space technology? How does this information differ from requirements information used by those engaged in primary applications of missile/space technology? What types of requirements information, through what channels, best facilitate the application of missile/space technology in the development of commercial products?

Chapter VIII

BEHIND THE TRANSFER OF MISSILE/SPACE TECHNOLOGY

The diffusion of technology is an extremely complex process as shown by the findings of this study which deals only with a relatively small part of the total picture. To step into this process and attempt to enhance diffusion of missile/space technology with reasonable chances for success would appear to require some basic understanding of the diffusion process itself. *

Little is known at present about the process of technological diffusion in industry. Research in the field has been limited, although several studies and programs are currently underway. This study was intended to contribute something new by identifying examples of technological transfer from missile/space programs to non-missile/space applications, and by producing partial insights into the flow of information accompanying such transfers.

While pursuing these objectives, a mass of related information was obtained which appears quite pertinent to the diffusion of missile/space technology. The related information consisted largely of comments made by representatives of the organizations contacted, both in interviews and in correspondence. The comments dealt with opinions, ideas, and experiences covering a wide range of subjects, such as government regulations, information retrieval, organizational structure, and marketing.

When the field work was completed, a need became apparent for developing some means to integrate and synthesize these varied comments for analysis purposes. Therefore, a conceptual framework was devised which is termed the "applications process" and which is discussed in Section A of this chapter. The comments then were grouped by similar subject matter and analyzed in a preliminary manner in terms of the applications process. The results of the analysis are presented in Section B of this chapter. The role of incentives in the applications process is discussed in Section C, and finally, the overall results of these analyses are related to the problems inherent in accelerating the commercial application of missile/space technology.

It is emphasized that more research needs to be done on the concept proposed here before its value as an analytical tool can be established. Additional research is also required to determine the applicability of certain observations made in Section B with the assistance of the applications process concept. While these observations may be valid for the firms contacted, they may not constitute valid generalizations for groups of firms or for all firms. In addition, it was not possible to thoroughly research the broad range of subjects embraced by the comments. It is recognized that certain of the comments made to us may be erroneous or biased; however, it may be valuable to know that they are believed true in some quarters, because beliefs are vital components of attitudes, and hence, actions. Within these limitations, the discussion proceeds.

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* Contrary to some opinions, this study has indicated that there has been and will continue to be an important transfer of technology from missile/space programs to commercial applications, although quantitative measurement of the transfer does not appear feasible. (See Chapters I and III.) Therefore, discussions of accelerating this process are dealing with realistic possibilities and not imaginary ones.

A. THE APPLICATIONS PROCESS

If a conceptual framework could be devised to synthesize the varied factors influencing the application of technology, it should have value to those in government (Office of Technology Utilization, NASA, Office of Technical Services, Department of Commerce, Division of Industrial Participation, AEC) who seek to accelerate the transfer of technology from missile/space programs to the commercial sector of the economy. It might also have value to individual firms.

The synthesis proposed here centers about the application of technology at the level of the firm, and is called the "applications process." We shall first develop a framework within which the process can be visualized as it pertains to the application of any kind of technology by individual firms. We shall then assume the framework has value as an analytical tool and proceed to use it to examine the commercial application of missile/space technology.

To define the applications process, it may be helpful to look first at the diffusion process of which it is a part. As noted in the previous chapter on "Information Flow," Katz described four components of innovation diffusion: 1) the movement of a specific innovation, 2) over time, 3) through identified channels of communication, 4) in a social structure.[1] Modifying this concept of diffusion to include technology (as opposed to a single innovation) related to industrial and missile/space activities and its applications, a chart is presented below illustrating the diffusion process with which we are concerned. Assuming the prior generation of technological knowledge, the diffusion process simply stated is concerned with the existence, communication, and application of this knowledge over time.[2]

Referring to the diffusion process chart, two concepts are introduced regarding the application of technology. One concerns the application of an individual innovation, consisting of the five stages defined by Rogers: awareness, interest, evaluation, trial, and adoption.[3] The other concept deals with the sum of all individual applications, at whatever stages, taking place in any organization or organizations, private or public. At one extreme, it can embrace only one firm or a division of a firm; at the other extreme, it can embrace the entire economy, including both private and public sectors.

The applications process, as defined here, consists of the latter concept, but it is restricted to the sum of all the individual technological applications taking place over time at the level of the firm. It can be conceptualized as a continuing process operating within the individual firm as well as within all or any group of firms. Being an integral part of the diffusion process, the applications process must be concerned with the diffusion process. However, we believe that it may be possible to describe the applications process in sufficient isolation to permit it to be used as an analytical and managerial tool. (At present, the diffusion process appears to be a cumbersome and difficult abstraction to conceptualize and the individual application concept is too restricted for our purposes.)

The first major element in the applications process is a dependency on merging or linking of technological information with market requirements information in order for applications to occur.* It does not appear that detailed knowledge of technology and

* In the decision-making stages, market requirements information includes demands for products to be sold by a firm as well as opportunities to apply technology internally to improve production methods, materials, management control, etc. It also includes all inputs required for new product decision-making in such areas as finance, plant and equipment, personnel, market strategy, distribution, etc.

THE DIFFUSION PROCESS OF INDUSTRIAL & MISSILE/SPACE TECHNOLOGY -- A SCHEMATIC OUTLINE

TECHNOLOGICAL KNOWLEDGE		COMMUNICATION OF TECHNOLOGY		APPLICATION OF TECHNOLOGY		
Two categories: the amount which exists and the amount which is being generated and added. In a static framework, most technological knowledge is: 1) recorded in documents, drawings, etc., deposited in libraries, bookshelves or filing cabinets around the world, 2) in the minds of men, or 3) in the communication pipelines.	+	A complex network of formal and informal channels through which technological knowledge flows. To effect communication (for our purposes here), three factors are necessary: 1) Retrieval or dissemination 2) Receipt 3) Retention (or awareness)	+	Individual technological innovations go through five stages when adopted and used: 1) awareness (or retention), 2) interest, 3) evaluation, 4) trial, 5) application.* Decision-making takes place in stages 2) through 5), linking technological and market requirements information. Rejection can take place in any of the last four stages. The application of technology can be visualized as the sum of all individual technological applications which are taking place in any firm, industry, government facility, etc., up to and including the national economy. The "applications process," as defined in this report, refers to the sum of all technological applications occurring only at the level of the firm, i.e., one, more, or all private companies.	=	Diffusion Process

* These five stages are taken from the definition of the adoption process as formulated by Everett M. Rogers, Diffusion of Innovations, New York: The Free Press of Glencoe, 1962, pp. 76-120. Rogers' concept of the adoption process appears to have been developed primarily from research on agricultural innovations, but the stages seem applicable to manufacturing. The application process differs from Rogers' adoption process in that it embodies all of the individual adoption processes which take place in one or more firms, as well as the factors which stimulate or hold back the occurrence of the adoption process.

markets need be possessed to spark the initial application idea; this can be supplied in the follow-up feasibility analyses. Formal and informal efforts to enhance the merging of market and technological information, of course, are quite common in industry.

A second major element consists of the factors influencing the frequency with which mergers occur between technological and market information within firms. It also considers the factors influencing the motivations of firms and individuals within the firms to act upon the resulting opportunities to apply technology, i.e., the disposition of the ideas flowing from the mergers. The factors which influence the frequency of the mergers and which influence their dispositions appear to overlap, and can be viewed as incentives or stimuli to the applications process on the one hand and as obstacles or barriers on the other hand.[4]

For the purposes of this discussion, the applications process can be rounded out by introducing a third major element which ties together the first two. The presence and operation of certain stimuli and barriers can be influenced by actions of company management and government. These actions, by definition then, can influence the degree to which technology is applied at the level of the firm.

There are a number of corollary elements which can be added to the framework based on our observations: It is possible to identify many of the stimuli and barriers which are present or absent in an individual firm or acting upon it; certain of the stimuli can also act as barriers, and vice versa; viewed relative to the general economic good, not all stimuli are "good" and not all barriers are "bad"; the applicability and relative importance of individual stimuli and barriers can vary considerably among different firms; some stimuli and barriers operate on the individual person, others on the institutional framework, and still others on both; and there are many unknowns surrounding the resulting effects of management and government action, on not only the stimuli and barriers (and hence on the application of technology), but also on the rest of the economy.[5]

Furthermore, it appears that most of the elements of the applications process can be formulated into a series of propositions serving as hypotheses about the process. Research could then be designed to test the hypotheses. As will become evident later, the research design should probably anticipate the ability to draw some generalizations for all firms, and other and differing generalizations for different types of firms, e.g., size, industry, and degree of government orientation. The previously cited work of Edwin Mansfield, in which he has identified some principal factors influencing rates of diffusion, provides valuable background for a segment of the applications process and can be accommodated in the proposed analytical framework.[6]

Further explanation of the stimuli and barriers may serve to illustrate the proposed framework of the applications process. The following tentative, incomplete listing of stimuli and barriers was compiled from information gathered during the study. No relative importance is attached to the sequence. To simplify the presentation, recognition is not given to individual items which can operate both as a stimulus and a barrier.

Incentives or Stimuli

Individual	Institutional
Salary	Profits
Invention awards	Diversification
Recognition and status	Organizational structure
Patents	Patents
Education	Personnel transfers
Dissemination media	Competition
Scope of job responsibilities	Continuity of the firm
	Market preemption
	Management sophistication

Barriers or Obstacles

Individual	Institutional
"Not invented here" concept	Uncertainty and risk
Reluctance to change	Reluctance to change
Time consuming paper work	Lack of knowledge
Narrowness of interest	Government regulations
Lack of knowledge	Capital requirements
Isolation	Proprietary data
Complexity and sheer mass of data	Security regulations
Limitations of the human mind	Organizational rigidities
	Incompatibilities between government and commercial R & D and production

The operation of many of these stimuli and barriers is examined in the next section as they apply to the commercial application of missile/space technology. The applications process, however, appears applicable to all industrial firms, as do many of the individual stimuli and barriers listed. Several of the institutional barriers, it should be noted, deal specifically with government contracting firms and would not apply to firms selling wholly to commercial markets, unless they explain in part why such firms have no government contracts.

B. STIMULI AND BARRIERS TO THE COMMERCIAL APPLICATION OF MISSILE/ SPACE TECHNOLOGY

The discussion thus far of the applications process has been somewhat abstract. Moving to a more practical level and using the proposed framework as a guide, we shall briefly review the miscellaneous information gathered during the study and determine how it is related to the commercial application of missile/space technology.

Brief summaries of comments made on 16 broad subject areas are presented. Each is accompanied by observations and speculations about how the application of missile/space technology is affected by the factors covered in the comments. It is emphasized again that these observations are preliminary in nature, and that further research is needed to determine their general applicability. Occasional suggestions are made for further research and for possible public and private action.

1. Government Patent Policy

No other area was the subject of as much comment and interest on the part of the industry people interviewed as that of patents. Major interest was focused on government patent policy, with NASA's policies at the center.

Since the subject of government patent policy is too technical and complex to be adequately dealt with here, reference is suggested to recent publications which deal specifically with the controversy.[7] In a nutshell, the question is whether ownership of (title to) patents arising from government financed work, especially research and development work, should reside with the contractor subject to a royalty-free, nonexclusive, irrevocable license to the government, or should be acquired by the government. The question continues, if title is acquired by the government, what should be the government licensing policy and who should police it?

At present, there is no uniform government patent policy; the desirability of a uniform policy is itself part of the dispute.* The Department of Defense (DOD) permits title to reside with the contractor with certain exceptions. NASA, on the other hand, automatically acquires title but may, under certain circumstances, waive rights to the contractor. DOD and NASA policies generally represent the opposing points of view in the controversy. Other federal agencies have their own patent policies, such as the Atomic Energy Commission, the National Science Foundation, and the Federal Aviation Agency, each containing its own variations.

For the most part, we encountered industry views quite similar to those expressed by industry representatives in the hearings before the House Subcommittee on Patents and Scientific Inventions.[8] The reasoning most frequently given for opposition to the government's taking title (commonly called "government title policy") follows.

> Comment Summary: Government-owned patents are less likely to be worked than if title resides with the contractor.[9] Government title policy can jeopardize title to company funded inventions. Eventually, the government title policy, if uniformly applied to all government financed research, would result in government ownership of a tremendous number of patents. This ownership would be accompanied by the necessity to determine who would be permitted to use these patents and under what conditions. Since more than half of all R & D in the U. S. is sponsored by the government, which in itself constitutes unprecedented control over technological advances, a government title policy would further strengthen the hand of government by giving it control over the use made of a significant proportion of technology. This contradicts the generally accepted role of the free market (modified by the traditional patent system) as the most effective economic decision-maker. It would subject a large proportion of U. S. technology to the limitations inherent in any complex activity controlled by central planning.

Reviewing these and other opinions and experiences cited by persons contacted during the study, we can make several tentative observations regarding the way in which government patent policy can affect the transfer of missile/space technology:

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* The term "government patent policy" as used in this report is restricted to the ownership controversy and does not embrace policies in such areas as anti-trust matters.

a. An individual firm normally has more incentive to exploit missile/space technology on a commercial basis if it has patent protection on part or all of the technology, device, process, etc.

b. If NASA were to adopt a patent policy similar to that of the Department of Defense (commonly called "government license policy"), it should serve to stimulate firms to seek commercial applications for missile/space technology developed within the firms with NASA funding.

c. On the other hand, patent protection can serve as a barrier to the commercial application of missile/space technology on the part of other firms denied use of patented inventions.

d. The value of patents to individual firms varies considerably, depending partly on the government-private sales mix of a firm and on the characteristics of a firm's products. Consequently, the impact of government patent policy is not uniform on all firms.

On the basis of our study, we are not able to support factually a conclusion as to whether the government's taking title to inventions has a net positive or negative effect on missile/space technological transfer.

2. Other Aspects of Patents

A number of other comments were made regarding patents which appear to have a bearing on the commercial application of missile/space technology.

Comment Summary: The process of writing up a patent application frequently advances the chances of an invention's being worked since the inventor and patent attorney together think through the invention, its significance, its applications, other ways of doing it, etc. The resulting document contains a great deal more information than the normal invention disclosure.

Therefore, the mere process of applying for a patent should act as a stimulus to the commercial application of missile/space technology. Invention disclosure forms, on the other hand, can act as a barrier, as indicated by another type of comment:

Comment Summary: In a government contracting organization, one of the least important papers to fill out, from the standpoint of line personnel, is an invention disclosure form. Line personnel tend to resent the "intrusion" of company patent personnel who take up their valuable time filling out "red tape" forms. The frequent company disclosure award of $50 to $100 is not considered sufficient by some individual R & D personnel to be worth the trouble of filling out disclosure forms.

However, management techniques have been applied to stimulate both the generation and reporting of inventions:

Comment Summary: A number of industry representatives reported that patent awards and invention disclosure quotas, when properly administered by management, help to overcome the inertia described in the previous comment. Several industry representatives also suggested that government awards to contractors or individual inventors would provide more incentive to report inventions--and to make inventions.

Many firms, of course, have invention disclosure award systems. These vary widely in detail of operation and in the firms' motivations for having established such systems.[10] But many firms knew little about the effectiveness of invention disclosure award systems, or about the relative merits of different company situations. This would appear to be a fruitful area for investigation.[11] This whole field, of course, is part of the broader subject of how to produce a creative environment.[12]

Regarding government awards for inventions, the National Aeronautics and Space Act of 1958 as amended authorizes the Administrator of NASA to make monetary awards to individuals or organizations for technical contributions having significant value to the conduct of aeronautical and space activities. Awards totaling $10,800 were recently made to a seven-man team at NASA's Manned Spacecraft Center for five inventions made in connection with the Project Mercury system.[13]

Information gained about the patent process during the study raises several questions which may affect the transfer of missile/space technology and it is suggested that they may be worth research:

a. How important are patents to the individual inventor? (e.g., how much prestige does he attach to patents in his name versus publications, apart from possible monetary considerations?)

b. How interested is he in filing company invention disclosures? What part do disclosure awards play in his feelings and how much does the size of the award influence his actions? How does he feel about failure on the part of his employer to file patent applications for his disclosures?

c. How significant a diffusion mechanism is the patent application for the firm preparing it? The patent itself, outside the firm?

d. Can NASA profitably make wider use of its technical contribution award powers?

In summary, there appear to be several opportunities in the general field of patents to increase both individual and firm motivation to find commercial applications of missile/space technology.

3. Proprietary Data

As with government patent policy, the subject of proprietary data is too complex to discuss in detail in this report, but it is mentioned briefly because it concerns the transfer of technology from missile/space programs to the commercial sector.

A number of complaints were voiced by industry representatives during the study about government regulations and government actions concerning proprietary data. Most of the complaints boiled down to this:

> Comment Summary: The federal government goes too far in what it requires contractors and, in turn, subcontractors to report as the result of work performed under federal contracts. Information required is often regarded as proprietary by the firm for a variety of reasons, e.g., a) it was developed with company funds, or b) it capitalized on years of pre-government contract company experience. In reporting such proprietary information, the contractor runs the risk of hurting its competitive position. The necessity of some requirement to reveal pertinent data upon completion of a government funded study was generally recognized by the individuals who voiced

complaints. However, they believed that more consideration should be given the company which performed the original development work, especially in cases where the firm had contributed its own funds to the effort. They also believed the government should be more discreet in revealing a firm's data to competitors.

In terms of the applications process framework, two major observations emerged from an analysis of the experiences and opinions reported to us regarding proprietary data:

a. To some extent government procurement regulations prevent exclusive possession by individual firms of missile/space technology and of related technology required by missile/space programs. This operates as a barrier in certain situations to the commercial application of such technologies on the parts of the originating firms. The added motivation for management action created by possession of trade secrets which could produce competitive advantages is missing.

b. Conversely, however, an inducement to reveal missile/space technology which the originating firm would like to keep proprietary can also act as a stimulus to commercial application in other situations by making the technology more accessible.

Many difficulties would occur in an attempt to estimate the net effect of the proprietary data problem on the transfer of missile/space technology to commercial use. In addition, the more pressing needs of the government to obtain missile/space technology for primary missile/space purposes would have to be considered in evaluating the secondary transfer objective, as well as the information requirements associated with calls for competitive bids by the government.

In spite of these difficulties, the proprietary data problem appears to be worth further attention in the context of technological transfer.

4. Security Regulations

One of the more obvious barriers to the commercial application of certain missile/space technology is caused by security regulations. Since this study did not include examination of classified information, no estimate can be made regarding the magnitude of this barrier.

While recognizing the necessity for security regulations, several viewpoints were expressed by a number of industry representatives which may indicate possible areas for change in the interest of better scientific communication. Generally these viewpoints fell into the following patterns:

Comment Summaries:

More effort should be made to declassify technology at the earliest possible date, consistent with national security requirements, especially in the basic research field.

The process through which a need to know is established should be less restrictive and less time consuming.

> Companies not engaged in government work felt they were left out of potentially valuable sources of technological information since they are denied access to many government research reports.[14]

It may be worthwhile to determine how much of a barrier security regulations are to the commercial application of missile/space technology. If this barrier is found to be significant, then the above viewpoints should be examined to determine whether it is feasible to modify the regulations to reduce the barrier.

5. Influence of Market Mix Served by Individual Firms on Technological Transfer

Whether a government contractor also serves non-government markets has a significant effect on the contractor's ability to apply missile/space technology to commercial applications, according to a number of industry representatives contacted. (The previous section on "Government Patent Policy" pointed out that the market mix served by individual firms also seemed to have bearing on the importance of patents to certain individual firms.)

For the purpose of the discussion which follows, most manufacturing firms can be divided into one of three categories:

-- All sales to commercial customers.
-- All sales to government customers, including government contractors.
-- Sales divided between commercial and government customers.

A further division can be made between the companies serving both markets: those which have established special divisions to handle government business (more prevalent among larger firms) and those which have not (more common among smaller firms).

> Comment Summary: Individuals in firms serving both markets were especially vocal about the need for management to be commercially oriented in order to market successfully to industrial and consumer markets, commenting that a military oriented sales department would have great difficulty marketing commercial products. Some added that the know-how gap between marketing government and industrial products was large, but the gap between government and consumer products was considerably larger.
>
> Several marketing people commented further:
>
> Comment Summaries:
>
> Smaller firms with both commercial and government identities would probably experience relatively more civilian applications of missile/space technology than large firms because the former could more easily effect a marriage of commercial applications with government related technology. Bigness was believed to be a barrier to the linkage of market and technological knowledge.
>
> A large number of potential commercial applications are probably lying dormant in firms having little or no commercial identity because they do not have the organization, know-how, or motivation to exploit them and because they may not have the knowledge necessary to recognize and evaluate potential commercial applications.

A similar situation probably exists in those large firms with commercial and government identities but which tend to isolate government work in separate divisions (which also may be separated geographically from commercial divisions).

The greater the number of commercial product lines manufactured by a government contractor, the greater tends to be the commercial application of space technology. The basis for this reasoning was that the opportunities for commercial applications seem to rise somewhat proportionately with the variety of commercial products being produced, i. e., broader market coverage. (If true, this viewpoint tends to counteract the first one above.)

The many comments made along these lines by individuals in a wide variety of firms were examined in relation to the actual transfers of missile/space technology identified during the study and reported in Chapter VI. This examination tended to confirm the validity of all but the last of the above statements. Therefore, we can make several preliminary observations about how the market mix of individual firms affects the commercial application of missile/space technology:

a. Selling to both the missile/space and commercial markets on the part of an individual firm tends to act as a stimulus to the transfer of missile/space technology into commercial applications.

b. Selling to the missile/space market alone acts as a barrier to such transfers.

c. Selling to the commercial market alone acts as a barrier to such transfers.

d. Geographical and organizational isolation of missile/space contracting activities by large firms with commercial identities tends to make the transfer process more difficult, and hence acts as a barrier.

These observations suggest what appears to be a rather obvious solution to accelerating the transfer of missile/space technology: get more firms to operate in both markets on an integrated basis. This is no panacea, however, as will be seen in the next section which discusses some of the problems which have arisen when commercial work is mixed with government work.

6. Incompatibility of Government Contracting with Commercial Operations

Many and varied management problems were reported by widely differing firms which were serving both the missile/space and commercial markets or which had tried to serve both markets in the past. These problems were generally attributed to differences in the nature of and in the conditions surrounding the two types of work.

Areas of difference most frequently cited included: marketing and patents (described in preceding sections), production and quality control, price, accounting, finance, research and engineering, security, ownership of plant and equipment, and bidding requirements.

Brief descriptions of a few types of problems reported may provide some insight into the incompatibilities of mixing government and commercial business.

Comment Summaries:

Missile/space products can be characterized by "reliability at any price," as opposed to "adequate reliability at a competitive price" for commercial products. This fundamental difference makes it difficult for many technical people with government contracting backgrounds to transfer to a commercial environment and operate effectively because they tend to overdesign commercial products, thus pricing the products out of competition. For example, one firm reported it had to replace its space experienced engineers with commercially experienced engineers when it attempted to redesign a space instrument for the commercial market at a competitive price.

The added operating costs required to meet government specifications regarding inspection, audits, reports, etc. frequently make it infeasible to produce both government and commercial products (even though quite similar) in the same facility. This has caused some companies to physically separate government and commercial manufacturing facilities.

Representatives of a number of firms, large and small, which were wholly or primarily oriented to the commercial market reported unsatisfactory profit experiences on government contracts. Blame was placed on failure of the government to allow what the firms believed to be legitimate business costs. As a result, most of these firms were unenthusiastic about securing future government contracts. On the other hand, a few different firms reported that through specialized departmental structure and separate bookkeeping procedures they had been able to operate successfully with government contracts.

One firm, largely a government contractor but having some commercial lines, reported that it had to resort to acquisition of established commercial firms to meet its commercial expansion goals. Failure to develop new commercial products internally was attributed to the incompatibilities of government and commercial work. Related experiences were reported by other firms which had sought to diversify into commercial markets.

Within the framework of the applications process, these incompatibilities present a dilemma to those who seek to accelerate the transfer of missile/space technology to commercial use. It was observed previously that transfer occurs most readily on an intra-firm basis. It logically follows then that transfer opportunities would tend to increase proportionately with the number of firms engaged <u>both</u> in missile/space and commercial work. Here the opportunities exist to link missile/space technology directly with commercial market requirements and capabilities within a single firm. On the other hand, here also is where severe management problems arise, caused by the very mixing of work that tends to create transfer opportunities. In an effort to overcome these management problems, there appears to have been a tendency in some firms to isolate government work from commercial work, thus apparently reducing the firm's ability to capitalize on transfer opportunities.

It is obvious, therefore, that the incompatibilities between government and commercial work act as a <u>barrier</u> to the commercial use of missile/space technology.

There is still another pertinent aspect to this discussion which presents another dilemma to the transfer accelerator. The primary purposes of missile/space programs, of course, are military and space.

> Comment Summary: Concern was voiced by one industry representative that the pursuit of by-products by government contractors was becoming a fad. In his opinion, there was a danger that contractors could become preoccupied with exploiting relatively unimportant by-product ideas, resulting in a dilution of their primary missile/space work.

There appear to be at least two suggested ways in which the government can help to partially solve these dilemmas, and the suggestions might be worth further consideration. One suggestion would be to sponsor management seminars designed to assist firms in solving the management problems created by mixing government and commercial work. Some firms seem to have handled these problems better than others, and the latter should be able to benefit by the experiences of the former. The second suggestion is discussed in the next section.

7. Company Organization and By-Product Exploitation

The transfer of missile/space technology to commercial use is hampered by a number of "gaps." Several of these are apparent from the industry experiences discussed in the preceding two sections: a) a gap between missile/space technological knowledge and commercial market knowledge, especially severe with firms which serve only the government or only the commercial market; b) a human adaptability gap experienced by many technical people when transferred from government work to commercial work (and perhaps vice versa); c) a management compatibility gap caused by differing requirements and operating methods as between government and commercial work; and d) an organizational gap in those firms which have found it desirable to isolate government work from commercial work, necessitated partially by gaps b) and c).

An attempt has been made by several aerospace firms contacted in the study to bridge these gaps by developing organizational mechanisms to handle commercial exploitation of missile/space technology. A number of factors appeared to have influenced the type of organizational structure selected for this purpose, such as company size, nature of company products, type and number of customers, and desires and interests of management. There are several ways in which missile/space technology can be exploited: licensing, franchising, outright sales of inventions, manufacturing and marketing directly by originating company, or combinations of these.

Two types of formal organizational structures to exploit by-products were encountered among these aerospace firms:

a. Separate division or subsidiary. Two aerospace companies have formed separate organizational units for the express purpose of by-product exploitation. Navan Products, Inc., a subsidiary of North American Aviation, was formed in 1957 to market by-products from the parent company and inventions from other companies. The Boeing Company established an Associated Products Division (BAP--Boeing Associated Products) in 1960 to market by-products originating in Boeing's other divisions. Both of these organizations screen by-products from the other divisions of the company and carefully select those which have the best possibility for industrial or commercial application. Exploitation can take various forms, including outright sale of inventions, licensing, franchising, and joint ventures. These organizations, however, do not take by-products from an operating division if the operating division desires to make the by-product a part of its product line.

b. Integrated organizational unit. Several other companies in the aerospace industry have established separate organizational units on a lower level to handle by-products. These units tend to be more integrated into the company's main stream of business and have less autonomy than those mentioned above. Some of these groups have been formed within the past year and it is not yet clear what direction they will take or what the scope of their activities will be. In at least one case, it appears that a group was formed to market a specific product, developed for missile/space needs, which promises to have good industrial potential. Organizations in this category include: the Diversified Products Department, Douglas Aircraft Company; Industrial Products Subdivision, Research and Advanced Development Division, Avco Corporation; Industrial Products Section, Lockheed Electronics Company; Industrial Products Group, Autonetics Division, North American Aviation; Product Exploitation Section, Hughes Aircraft; Product Planning Section, Marquardt Corporation.

In general, most of the other large and medium sized firms contacted which served both government and commercial markets followed the pattern of exploiting by-products within the originating division or within another division handling similar products. In some cases, by-products are licensed to another company if they do not fit the company's product lines or for other reasons. The lack of apparent formal mechanisms to process by-product ideas, however, caused us to wonder how many profitable transfer opportunities were missed in some of these firms in spite of the normal operation of internal invention disclosure and suggestion systems.[15]

No special organizational mechanisms were noted in small firms contacted, and perhaps none is needed or would prove feasible.

On the surface, at least, the gap-bridging mechanisms described briefly above have appeal. Since the coming of the Industrial Revolution, there undoubtedly has always been a gap between the firm having potential by-product ideas and the firm or entrepreneur seeking new products. For the reasons discussed, this gap has expanded into several types of gaps with the appearance of the missile/space program, and the resulting combination of gaps appears to be a formidable deterrence to commercial applications of missile/space technology. If gap-bridging organizational mechanisms are effective (and it seems reasonable to assume they are or could be made effective, especially in medium to large firms), then they act as stimuli to such commercial applications. Conversely, the absence of such organizational mechanisms coupled with the nature of certain forms of company organization can act as barriers to these transfers.

There are other mechanisms which appear to act as gap-bridges. For example, some universities, such as the California Institute of Technology, have active research foundations which license new developments to industry for application. The Patent Development Division of the Research Corporation may also serve as a gap-bridger in its capacity as patent evaluator and processor and licensing agent for 130 academic, scientific and other non-profit organizations.[16]

It may be too soon to evaluate fully the effectiveness of certain of these gap-bridging mechanisms, but a preliminary evaluation would seem to be worthwhile. Therefore, referring to the end of the preceding section, our second suggestion regarding how the government might help to partially solve the dilemma outlined would be to sponsor or to encourage research to determine the effect of organizational structure on the commercial application of missile/space technology. If the research results indicated that organizational gap-bridging mechanisms and other techniques are effective and workable, then the government could give publicity to these findings and encourage the adoption of such mechanisms and techniques on the parts of individual firms.

This appears to be an especially fruitful area in which specific attempts to optimize the exploitation of transfer opportunities may pay off.

8. Dual Risk Taking in Financing New R & D Areas

One interesting idea was expressed by an industry source as to the greatest commercial contribution of missile/space programs.

> Comment Summary: When certain ideas are in their infancy, such as microsystems electronics was a few years ago, industrial firms will not risk large R & D expenditures when no reasonable pay-outs are foreseeable--unless there is risk sharing on the part of government sponsored R & D. Many of the recent state-of-the-art advances in electronics fall into this category, although tracing this kind of transfer is extremely difficult because hindsight cannot reconstruct accurately the degree of motivation provided at the time of government cost sharing.

To the extent this comment is correct, then such dual risk taking on the part of the government and industry has acted as a stimulus to both the commercial development and application of technology shared with missile/space programs.

9. Motivations to Perform Government Work

The factors which motivate firms to undertake government work are related indirectly to the transfer process. We have observed that the transfer opportunities of missile/space technology tend to increase with the number of firms engaged in both government and commercial work. Theoretically, therefore, the transfer process could be enhanced by increasing the number of commercial firms doing government work. There are more significant criteria, however, that should govern the entry of firms into missile/space markets, as indicated in the recently published book, The Weapons Acquisition Process; for example, too many competitors tends to degrade rather than to improve the performance of the industry.[17] Many of the findings and conclusions reported in this book regarding motivations to perform government contract work, and the accompanying risks and benefits, were substantiated by industry comments made during the performance of our study.[18] Certain of the reported motivations for seeking government work, however, are worth reporting here to aid in understanding the transfer process. Generally, they fell into the following categories:

> Comment Summaries:
>
> Representatives of a number of large commercially oriented firms stated they could not afford to be outside the missile/space program effort in order to protect their companies' future competitive positions in both government and commercial fields.

Several established commercial firms indicated government work provided a medium through which to enter into new fields on the ground floor.

One large firm recently made the decision to undertake its first government R & D contract because of anticipated spill-over benefits to its commercial endeavors.

A number of smaller firms reported government work enabled them to get a start, from which they later branched out into commercial markets.

A few commercially oriented firms reported undertaking missile/space work to fulfill their obligation to contribute to the nation's security.

While not specifically mentioned, short term profit motives, as well as longer term profit motives implied in the first three categories above, were present in many decisions to perform government work.

These motivations, of course, act indirectly as a stimulus to the transfer of missile/space technology as noted at the beginning of this section. However, to the extent the expectations embodied in these motivations are not realized, they tend to reduce the number of firms engaged in both government and commercial work, thus acting as a barrier to transfer.

10. Special Problems of Small Business

The role of small business in performing government contract work has received considerable attention in recent years, both in the executive and legislative branches of the federal government. Many of the comments made by small businesses during this study reflect what has already been brought out, but some are presented here since they appear to have a bearing on the transfer process.

In general the comments fell into two types: those reflecting the disadvantages of being small; and those reflecting a feeling of mistreatment at the hands of government or larger firms. They are not segregated by type in this discussion because elements of both are contained in some of the comments. Since some were quite emotional, it is emphasized that they represent individual opinions which may or may not be factual or representative. For the most part, the comments originated with those small firms which reported no instances of transfer from the missile/space program.

The following categories generally cover the problems expressed:

Comment Summaries:

A number of firms felt they had capabilities which were being denied to the missile/space effort because of the difficulties experienced by small businesses in gaining a foot-hold in this market.

Visits to government agencies by company sales personnel are excellent sources of market information, but geographic distances make it too costly for a small manufacturer to cover comprehensively the various agencies which should be visited.

Certain small firms supplying materials and specialized instruments on a subcontract basis voiced concern over their inability to evaluate their total potential markets among the larger prime and subcontractors. In addition, their remoteness from eventual application of their products, sometimes further complicated by security restrictions, prevented their acquisition of knowledge which they felt would be helpful to better performance.

A few said better access was needed to testing equipment which was too expensive to purchase but which was required in order to maintain quality demanded by prime contractors.

The small manufacturer, in general, is faced with radically new problems in attempting to serve the missile/space industry. These problems make entry into the industry a costly process which requires employing specialists.

The high cost of soliciting space business, the long time lag between development and production, and the frequent failure to obtain contracts after heavy investment in proposals combined to cause several firms to lose interest in pursuing space contracts.

Large firms get most of the R & D contracts, several small firms reported, leaving the smaller firms dependent on their own R & D funds to design products for missile/space markets. Some have found this extremely difficult, since they do not possess the equipment or know-how needed to redesign their commercial products to meet the exotic space program requirements.

NASA and DOD should contract directly with smaller firms and not channel procurement through prime and large subcontractors, according to several comments.

One small manufacturer stated that the larger contractors call on small firms for specialized assistance but, once given, there is a subsequent tendency for the large firms to perform the operation themselves.

One job shop firm was very critical of what it believed to be picayune and unrealistic requirements on the part of aerospace firms, causing expenditures of much unnecessary time, to the point that the job shop firm tries to avoid aerospace business.

Some of these opinions and reported experiences serve to emphasize the incompatibilities between government and commercial work, discussed previously. Others, however, are important to the context of this report in another way when viewed from the framework of the applications process. These are the ones which indicate the handicaps faced by a firm when entering the missile/space market just because it is a small firm. For example, the costs of visiting widely separated government facilities, of hiring specialized personnel, and of purchasing specialized equipment serve as <u>barriers</u> to entry, and hence to transfer.

If successful, efforts on the part of the government to alleviate some of these disadvantages of being small might serve as a stimulus to the transfer of missile/space technology. Not only would successful efforts along these lines tend to increase the number of firms serving both government and commercial markets (which, as previously observed, tends to increase transfer)* but such efforts would increase intra-firm transfers of missile/space technology among smaller firms--in which transfers may tend to occur more readily than in large firms. The latter point, however, requires further research before the effect of company size on transfer can be stated with certainty.

In summary, there appear to be areas in the small business picture worthy of further consideration as to how the transfer process can be accelerated.

11. Increasing Volume, Complexity, and Degree of Specialization of Technology

The rapid advances being made in science and technology--while presenting many opportunities--are causing serious problems. One is how to keep up with the sheer mass of information available. Charles P. Bourne of Stanford Research Institute summed up the situation quite succinctly:

> The world's scientific community is presently generating a flood of technical literature, and much of it is not getting into hands of people who could use it. It is probably missing these people for two main reasons: only a fraction of the literature is covered by abstracting, indexing, or citation publications; and only a fraction of those people who could use the information are familiar with the literature or aware of the tools and facilities for locating the information . . .[19]
> . . . realistic estimates seem to point to a world-wide publication of about 15,000 significant journals, and one million significant papers per year.[20]

The literature problem multiplies because literature is being generated in ever increasing quantities. While numerous organizations and individuals are working to find solutions, a panacea is not in sight.**

Many comments were made during this study reflecting the ramifications of the literature problem in industry. Generally, they fell into four categories.

Comment Summaries:

The small organization does not have the manpower required to derive full value from the information now available from NASA and other sources.

Better classification of existing information and less duplication in dissemination would be helpful.

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* As noted in the preceding section, this may not be a desirable goal if the entry of more firms into the missile/space industry would have harmful consequences to the performance of the industry. This is a difficult and complex question, embracing also the subject of economic concentration.

** A listing and brief descriptions of this research are published semi-annually by the National Science Foundation in a series entitled, Current Research and Development in Scientific Documentation, available from the Government Printing Office.

The need is not for an increased flow of information but for an improvement in quality of the present flow.

To cope with the flood of new technical knowledge, management should hire the most competent professional talent available to identify and monitor the sources of new knowledge.

Of interest along these lines is a statement by William T. Knox, made in his 1959 testimony to the House Committee on Science and Astronautics:

> . . . Our experience at Esso Research & Engineering with information research work leads us to believe there is a wealth of new ideas and new applications of existing ideas which can be made available to those who will take the time to study the literature. The main problem is putting high quality scientists and engineers to work in this field. We feel it is very important to realize that the United States has no shortage of information, but a real shortage of people who are talented and trained and motivated to make use of this information. (Emphasis added.)[21]

Other comments ranged outside the literature problem into the implications of the increasing volume and degree of specialization of technology.

Comment Summaries:

More effort should be expended to identify possible commercial applications of missile/space technology. (No suggestions were offered regarding who should make this effort.)

There are so many poor application ideas proposed for every good idea that the good ones often get buried and are lost with the bad.

Salesmen, long a source of new application ideas, are experiencing difficulty in keeping up with new technological developments within their firms and hence are not as productive as formerly in generating new uses for newer products. Two solutions suggested: more highly trained salesmen, and periodic visits to customers by R & D personnel.[22]

The problem of rediscovering that which is already known has become more acute.[23]

It is obvious that the sheer mass and relative inaccessibility of published technical literature in the missile/space field act as barriers to commercial applications of missile/space technology.

Recognizing these factors, NASA has recently contracted with several research institutes and a university to identify specific commercial applications of space technology and to disseminate their findings to commercial industry. This is an interesting program to watch because, if successful, it could be a strong stimulus to the transfer process.

The specialized technical information dissemination services of the various federal agencies (some of which are mentioned in Chapter VII) also act as stimuli to transfer, as do private technical, professional, and trade publications, books, professional and trade meetings. There is considerable room for improvement in these dissemination media, however, judging by the comments made during this study.

Apart from these considerations, there is another area which appears worthy of thought and possible action by the government. Our experiences in this and other studies lead us to agree with Bourne that relatively few people who could make use of the technical literature (especially in commercial industry) are familiar with it or know how to get access to it.[24] It is suggested, therefore, that the government consider the feasibility of sponsoring seminars designed to increase the literature awareness and the retrieval skills of appropriate individuals in commercial industry. Since motivation to learn about the technical literature appears to be lowest among those who might most profit by this knowledge, it may be advisable also to consider ways to increase the motivation of this group.

It has been possible here to treat only very briefly the subject of technical information. If considered in some depth within the framework of the applications process, there undoubtedly would be many other possibilities worth exploring to accelerate the transfer of missile/space technology.

12. Pressures of Time Schedules

Closely tied to the comments reported in the previous section on the increasing volume of scientific and technological knowledge were several observations concerning problems imposed on individuals by limitations of time. These were raised in several different contexts.

> Comment Summary: On the philosophical side, the dean of a business school pointed out that a major problem was developing regarding how a manager should divide his time between acquisitions of knowledge and the application of knowledge to decision making.[25]

It appears that the same question could be raised for the working scientist and engineer, the science and engineering student, and for a variety of other professions.[26]

> Comment Summary: A different aspect, touched on previously in another context, was raised by several industry representatives to the effect that R & D people engaged on government contract work were too pressed by time schedules to give much, if any, thought to possible commercial applications of their work. In addition, some observations went further to indicate that there was usually little incentive or motivation present to encourage such thinking, particularly in the firm or corporate division devoted exclusively to government work.

While some individuals undoubtedly are stimulated by time pressures to increase their outputs, limitations of time will always pose barriers to the transfer process. Recognition that these barriers exist should assist in designing transfer acceleration efforts which can operate feasibly within the time availability of individuals affected. For example, better teaching methods, more refresher courses, better dissemination methods, and techniques for more efficient utilization of time on an individual basis are receiving attention and should help to alleviate the problem.

13. Scope of Individual Interests and Knowledge

Comment Summary: The average scientific researcher, according to a number of people contacted in industry, tends to concentrate his interests on his scientific objective. He tends to be relatively uninterested in the eventual commercial applications of his discoveries or of those made around him. (There are notable exceptions to this generalization, of course.)

We sensed this ourselves in interviews with research oriented scientists and engineers in both industry and government, as well as within university research groups.

Comment Summary: In fact, a number of R & D space scientists told us they never gave commercial applications a second thought, since their primary objective was to produce space accomplishments as rapidly as possible.

This can be considered commendable or not, depending on the viewpoint.

Comment Summary: A few individuals contacted, on the other hand, believed that the innovator himself should be the best source of information concerning commercial applications of his work. This was contradicted by the observations already reported that application ideas come about only when a marriage is effected between technical knowledge and market knowledge, and the innovator frequently does not possess the latter.

Disagreement may have been due to different frames of reference on the parts of the individuals who made the comments. For example, the basic researcher, by nature of his work, is usually thought to be less concerned with practical applications than the applied researcher. Referring to basic research contributions at the Bell Labs, Addison White wrote:

> . . . It is then often up to the research 'managers' to see the connection between a scientific discovery and the technology, and to alert the appropriate applied research or development group to the possibilities. [27]

Some industry representatives interviewed may have had the basic researcher in mind, but it was clear that others were also referring to the applied researcher in commenting about the low degree of interest in commercial applications.

In any event, most of the opinions and experiences reported by industry representatives indicated that narrowness of interests among many scientists and engineers acted as a barrier to the transfer of missile/space technology.

From the standpoint of the applications process, we offer two suggestions which may aid in reducing this barrier:

a. In every firm there are certain individuals who can link technological knowledge to commercial application needs and opportunities more easily than others. If President Kennedy's proposals are adopted ". . . to make the by-products of military and space research easily accessible to civilian industry" [28] such individuals become crucial to the success of the President's proposals. Therefore, it appears that efforts should be made to identify and to know more about the industry people who can perform the linkage function.

b. Management literature in recent years has devoted considerable attention to the need for bringing together technological and market knowledge in the context of new product planning. The American Management Association and the Small Business Administration have been especially interested in new product planning. It seems that application of management knowledge developed in this field to the problem of missile/space technological transfer would be quite productive.[29]

14. The "Not Invented Here" Concept

A commonly used term in industry, "not invented here," refers to a tendency on the part of the individual scientist, or working group of scientists, to be unwilling to accept freely information not developed by himself or the immediate group concerned.

Comment Summaries:

This tendency was regarded by a number of industry representatives as a very real barrier to diffusion of technological information, not only between different organizations but also between different divisions within a given firm.

One explanation attributed this behavior to a form of pride of authorship--the wish fathering the belief that one's ideas are superior to others'.

(Bernard Barber has offered a number of explanations for the related but somewhat broader problem of resistance to scientific discovery.)[30]

Comment Summary: The "not invented here" concept received part of the blame by one individual for the failure of a dissemination program his company had tried and abandoned a few years ago. Under the program, one division of the firm could obtain in-house financial sponsorship of an idea which it hoped to develop for presentation to another division for the latter's application. The program failed--not because divisions would not develop ideas with in-house funds for this purpose--but because the other divisions, who were thought to have interest in the developments, would not accept them.

Unwillingness to accept another's ideas--or any change for that matter--is not a behavior characteristic peculiar to technical people. But its operation as a transfer barrier within the scientific community would make for interesting research and possibly useful results to those who are attempting to accelerate technological transfers.

15. Communication Between Technical and Management People

It was apparent from the remarks of a number of industry representatives that applications ideas do not always flow freely between the technical staff and the members of management within a firm. This problem, in the larger context of communication between management and professional staff, has received considerable attention in recent years in management seminars and in the literature.[31]

Comment Summaries:

With regard to new product ideas flowing as a by-product of government research, a planning executive of one firm contacted stated that successful transmission of such ideas is frequently aided if the proponent happened to know personally the company president or some other influential member of the management team. He believed this was especially true in cases where the firm has no system established to process such ideas.

The president of another firm expressed the situation more forcefully. In order for any new idea to be developed to the point of a marketable product, two basic conditions usually must be met: 1) the inventor must have intense persistence, confidence, and singleness of purpose, and 2) he must be successful in interesting someone sufficiently close to the purse strings in the company management to act as a sponsor, translator, and go-between. The "sponsor" must be someone trusted by management whose objectivity can counteract the suspicion created by the inventor's love of his invention. [32]

In a recent Denver Research Institute study of new product problems in small manufacturing companies, it was found that these two conditions sometimes were met by one individual, called a "product champion," who possessed the qualities of both an inventor and a promoter. [33]

Numerous other related ideas were expressed during the study, such as the following:

Comment Summaries:

Vocabulary differences cause breakdowns in communication between scientists and managers.

There is too little mutual understanding of the administrative and the scientific points of view, which are quite different. [34]

Much of the literature dealing indirectly with new application opportunities is read only by technical people and does not get into management hands.

An analysis of these comments leads to two rather obvious observations about the transfer of missile/space technology to commercial applications:

a. Communication difficulties between technical and management personnel within a firm tend to prevent linkage of technological knowledge to market knowledge and hence they act as a barrier to transfer.

b. Active support of an innovator's idea on the part of a leading company official enhances the chances for acceptance and application of the idea and hence acts as a stimulus to transfer.

This appears to be an area which could be examined profitably by individual firms to a greater extent than has been done to date. The examinations might focus on how to create environments in which greater internal flows of ideas would be stimulated.

16. Personnel Transfers and Job Changes

A number of individuals in both government and industry expressed the belief that the flow of people within and between organizations is one of the most effective diffusers of technology.

Comment Summaries:

For example, the normal promotional process of both management and skilled personnel results in intra-company transfers from space to non-space departments in one commercial firm with large space contracts. According to an official of the firm, these people carry with them "education" received in space work, which brings into play in their non-space assignments new ideas relating to reliability, quality control, and testing processes, as well as higher skills in mechanical functions.

A few instances were reported of companies which consciously try to transfer technical employees within the firm for the express purpose of diffusing technology. No details, however, were obtained concerning the operation and results of such transfers.

Several industry representatives stated the flow of people from missile/space activities to commercial activities was undoubtedly resulting in substantial transfer benefits to the civilian economy, although almost impossible to identify and measure. (None commented, however, whether the flow of people from missile/space to commercial activities was large or small.)

It is logical to conclude that the flow of individuals from missile/space work to commercial assignments acts as a stimulus to the commercial application of missile/space technology. In view, however, of the difficulties brought out earlier which many technical people have experienced in adapting to a commercial environment from a government contracting environment, it is suggested that inquiry be made into the operation and results of the planned flow of technical people in those firms pursuing such a formal policy. Such an inquiry should indicate whether formal transfer programs would be worth encouraging in firms serving both missile/space and commercial markets as a means to stimulate commercial applications of missile/space technology.

C. ROLE OF INCENTIVES

The above 16 sub-sections have focused attention on a number of factors influencing the commercial application of missile/space technology. It was observed that some of these factors act as stimuli to the process, others as barriers, and still others as both stimuli and barriers.

There is nothing unique in noting that there are stimuli and barriers operating at the level of the firm. Almost every human endeavor encounters stimuli and barriers. However, the information supplied by the individuals contacted in this study has enabled a start to be made toward identifying specifics which appear to influence the applications process. Also, the framework developed to analyze these specifics appears to have value in identifying and evaluating alternative means to accelerate the transfer of missile/space technology.

In a competitive enterprise the role of incentives is well known. The role of incentives in the generation and application of technology, however, is less known and sometimes overlooked; furthermore, it appears to be changing. For example, in a recent study of scientists in research organizations, Howard M. Vollmer of Stanford Research Institute investigated the role of incentives in the general performance of professional personnel. Commenting on modern industrial organizations, Vollmer stated:

> . . . Organizations may become dependent upon professional initiative and originality, and professional incentives may become more important than formal administrative arrangements and job specifications. Scientific personnel participate in organizational activities for monetary rewards, but money is not ordinarily enough incentive. Modern enterprise may ultimately have to modify bureaucratic patterns of organization so as to provide a working environment that is intellectually challenging and that provides a greater opportunity for professionals to participate in work-related decisions. [35]

We have seen that incentives have a varied role to play in the diffusion of technology. They must motivate individuals and organizations to generate technological knowledge; to disseminate technological knowledge; to look for and receive technological knowledge; to link market information with technological knowledge; and to exploit feasible opportunities to apply technological knowledge, e.g., to produce products, materials, or services. We have also seen that incentives take many forms; some operate on the organization and others on the individual.

We conclude from our research that incentives may be able to play a considerably larger role than they do now in a national goal of increasing the generation and diffusion of technology. Such a goal deals largely with the motivation of human beings and incentives properly formed are powerful motivators of people. The success of the AEC's uranium exploration incentive mechanisms is a dramatic example.

This chapter has suggested various possibilities for increasing the transfer of missile/space technology to the commercial sector by adding to or increasing the stimuli in the process. In addition, possibilities have been suggested for removing or reducing the barriers in the process, which should have the effect of adding power to existing stimuli.

The problem of deciding how to change what in order to increase the transfer process is not an easy task, however, for reasons discussed next.

D. SOME UNKNOWNS IN ATTEMPTING TO ACCELERATE THE TRANSFER OF MISSILE/SPACE TECHNOLOGY

One overriding observation emerges from the preceding discussion of factors influencing the transfer of missile/space technology to commercial applications: the process is complex and little understood. This study has merely scratched the surface and provided partial insights into the transfer process.

Caution is usually advisable in dealing with any area of endeavor which is surrounded by unknowns. The transfer process is such an area; the varied viewpoints on just the magnitude of the transfer which has taken place to date is testimony to the presence of major unknowns. A number of these unknowns have been brought out in this chapter. Two others may serve to illustrate further the lack of understanding.

First, the interrelationships of the application of technology and economic activity are not well understood. For example, at what rate should new technology be generated and at what rate should it be applied in the civilian sector of our economy? There has been a tendency on the part of some people to talk in terms of maximizing these rates. Viewing the latter rate in light of the applications process, this would mean that as many linkages as possible should be effected and exploited at the earliest possible dates between technological knowledge and market requirements information. This does not appear to be a desirable goal.

It is conceivable that a nation could devote so much of its resources to generating new technology that the point of diminishing returns would be exceeded, or that other sectors of the economy would suffer disproportionately to the resulting technological gains, or both. In addition, a nation could employ its capital inefficiently by applying new inventions too rapidly.* For these and other reasons it appears that the goal in this instance should be to "optimize" rather than "maximize" the rates of generation and application of technology. But what are these optimum rates? We have seen no evidence that they are known factors.

It follows, therefore, that we really do not know how much transfer of missile/space technology to commercial applications there <u>should</u> be.

Second, and closely related to the above, it would be foolhardy to rush through changes in the hope of eliminating certain barriers or in the hope of creating certain stimuli to the commercial applications of missile/space technology without first giving careful consideration to secondary and tertiary effects of such actions. Assuming, for example, that selected institutional changes would cause an increase in the total application of technology, how would market structure be affected, and how would motivations to increase technological applications differ among firms operating in different market structures? This is a difficult question, on which there is sure to be considerable disagreement, as can be seen in a recent Committee for Economic Development paper by Edward F. Denison:

> . . . Some observers (especially Joseph A. Schumpter) have argued that monopolies will devote more resources to research than competitive enterprises because of their greater ability to preempt the gains, so that a business structure consisting of monopolies will progress more rapidly than a competitive society. This view is vigorously disputed on the grounds that monopolies tend to become stagnant and unprogressive, and more importantly that historical studies fail to reveal any special tendency for major advances to emanate from monopolistic firms.[36]

Unknowns of these magnitudes indicate that severe difficulties would be experienced in attempting to accelerate the transfer of missile/space technology on a large scale. This is not to suggest that such attempts are not worth experimentation; rather, this suggests that greater efforts should be made to understand technology--its generation, communication, application, and its impact on the economy. An increase in this kind of understanding should greatly enhance the probability of success of any transfer acceleration effort.

This point can be illustrated in a different way. We found concern among individuals in industry, independent research laboratories, universities, and government about

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* For example, public and private action designed to stimulate commercial applications of missile/space technology conceivably could result in an excessive application rate. This, in turn, could result in higher costs to existing manufacturing firms.

the role of private versus public action in matters relating to technology. Some of these have been reported and to them we add one of our own. In the context of the proposals made by President Kennedy to increase the diffusion of technology generated under government sponsorship to civilian industry, we are concerned lest lack of understanding of the diffusion process will result in administering the wrong drug to the patient.

What we have learned from our work in this study indicates that understanding is particularly lacking at the most critical point of the diffusion process: application of technology at the level of the firm. It is of little use to generate and communicate technological knowledge unless it is applied.

It is hoped that this discussion of the applications process, and of some of the factors which act as stimuli and barriers to the commercial application of missile/space technology, will serve to increase understanding of what takes place at the level of the firm. It is emphasized, however, that this has been a preliminary exploration of the subject, and that there are many unknowns still to be explored.

Analyzing current trends in the American business scene, Margaret Mead recently wrote in the Harvard Business Review:

> At present . . . there are whole areas in our economy in which it is virtually impossible to get any program under way because of . . . confusion between the proper roles of government and private industry. The difficulties are, of course, greatest in those situations in which success depends on solving the problems of overlapping, or more exactly, shared public and private responsibility. The precedents of successful sharing are as yet too few for Americans to have worked out a viable ethic. (Emphasis added.) [37]

A final observation regarding the discussions presented in this chapter: We do not have what Margaret Mead calls a "viable ethic" to guide shared public and private responsibility. We do not have adequate knowledge of the impact of technological applications on our economy. We do not have a good understanding of the technological diffusion process. Therefore, it appears that this nation should proceed cautiously and thoughtfully in efforts to stimulate commercial applications of missile/space technology.

The arguments in favor of stimulating technological transfer are strong and logical. The question thus becomes not what should be done, but how much to do and how to do it.

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In a few instances descriptions of reference material are enclosed in brackets. This indicates the reference was unpublished (mimeograph or near-print) and publication data not known. Copies of the material should be available from the organization cited.

The following abbreviations have been used:

ARS--American Rocket Society

ASTIA--Armed Services Technical Information Agency
(Arlington Hall Station, Arlington 12, Virginia)

DMIC--Defense Metals Information Center
(Battelle Memorial Institute, Columbus, Ohio)

G. P. O.--Government Printing Office
(Washington 25, D. C.)

IRE--Institute of Radio Engineers

ISA--Instrument Society of America

NACA--National Advisory Committee for Aeronautics
(Predecessor to NASA)

NASA--National Aeronautics and Space Administration
(Washington 25, D. C.)

NSF--National Science Foundation
(Publications available from Government Printing Office)

O. T. S.--Office of Technical Services
(Department of Commerce, Washington 25, D. C.)

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Chapter VII.

DIFFUSION OF TECHNOLOGICAL INFORMATION

1. Wilbur Schramm says that two things can confidently be said about communications effects:
(1) A message is more likely to succeed if it fits the pattern of understandings, attitudes, values and goals that the receiver has.
(2) Communications effects are resultants of a number of forces, and the disseminator can really only control one of these. He can shape his message and he can decide when and where to introduce it. He cannot count on controlling (a) the situation in which the message is received and in which response takes place; (b) the attitudes and personality state of the receiver; and (c) the receiver's group relationships and standards.
Wilbur Schramm, The Process and Effects of Mass Communication (Urbana, Illinois: University of Illinois Press, 1954), pp. 16-7.

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5. Such as: Bryce Ryan and Neal Gross, Acceptance and Diffusion of Hybrid Seed Corn in Two Iowa Communities, Bulletin 372 (Ames, Iowa: Iowa State College of Agriculture and Mechanical Arts, 1950).

6. Rogers, op. cit., p. 4.

7. James Coleman, et al., "The Diffusion of an Innovation Among Physicians," Sociometry, 20 (December 1957), pp. 253-70.

8. Elihu Katz, "The Social Itinerary of Technical Change: Two Studies on the Diffusion of Innovation," Human Organization, 20 (Summer 1961), pp. 70-82.

9. Charles Y. Glock, et al., The Flow of Information Among Scientists (New York: Columbia University, Bureau of Applied Social Research, 1958).

10. A project resulting in some similar findings is reported by Saul and Mary Herner (Under Contract AT(49-12)-1869), The Use of Atomic Energy Commission Technical Information Tools and Services (Washington, D.C.: Herner and Company, February 1962).

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12. Science, Government and Information, A Report of the President's Science Advisory Committee, January 10, 1963. (G. P. O.)

13. Directory of R and D Information Systems, Headquarters, Office of Aerospace Research, USAF, AD262958. (O. T. S.)

14. Specialized Science Information Services in the United States. Report prepared by Battelle Memorial Institute for National Science Foundation, November 1961. (G. P. O.)

15. Glock, et al., op. cit., p. 15.

16. "But, when we consider most major aspects of space art, such as trajectories and orbits, guidance and control, the structure and fabrication of space vehicles, and rocket motors, we are forced to conclude that space art is rather an adaptation and an exploitation of the world's science and technology than a truly independent science and art."
J. R. Pierce, "Satellite Relays," [paper, Bell Telephone Laboratories, Murray Hill, New Jersey, January 11, 1962], p. 4.

17. Current Research & Development in Scientific Documentation, No. 10, National Science Foundation, May 1962, NSF-62-20. (G. P. O.)

Chapter VIII.

BEHIND THE TRANSFER OF MISSILE/SPACE TECHNOLOGY

1. Elihu Katz, "The Social Itinerary of Technical Change: Two Studies on the Diffusion of Innovation," Human Organization, 20 (Summer 1961), pp. 70-82.

2. The definition goes beyond the communication of technology, to include the application of technology. This is in accord with the concept of the diffusion process used by Edwin Mansfield. See for example, "Diffusion of Technological Change," Reviews of Data on Research and Development, No. 31, National Science Foundation, October 1961, NSF-61-52. (G. P. O.)

3. Everett M. Rogers, Diffusion of Innovations (New York: The Free Press of Glencoe, 1962), pp. 76-120.

4. After this section was written, we noted with interest an article by James B. Quinn and James A. Mueller entitled "Transferring Research Results to Operations," Harvard Business Review, 41 (January-February 1963), pp. 49-66, which discusses many of the stimuli and barriers we found in this study. They used a framework called a "transfer system" which is similar in many respects to what we call the "applications process." We also noted a similar concept in a recommendation to NASA appearing in A Review of Space Research, Report of the Summer Study conducted under the auspices of the Space Science Board of the National Academy of Sciences at the State University of Iowa, June 17-August 10, 1962, Publication No. 1079 (Washington: National Academy of Sciences -- National Research Council, 1962), p. 16-6. The recommendation stated in part, "...it is important to...analyze the factors pushing toward and against the adoption of innovations."

5. Robert A. Solo has emphasized the importance of the "creative response" of private industry to "spillover" opportunities from military/space programs. The proposed analytical framework of the applications process can be related to this

concept, since the degree of "creative response" appears to be dependent upon the presence and operation of the stimuli and barriers. See his article, "Gearing Military R & D to Economic Growth," Harvard Business Review, 40 (November-December 1962), pp. 49-60.

6. "Diffusion of Technological Change," loc. cit. footnote 2; and "Innovation in Individual Firms," Reviews of Data on Research and Development, No. 34, National Science Foundation, June 1962, NSF-62-16. (G. P. O.)

7. Several publications of The Patent, Trademark, and Copyright Foundation have been devoted in whole or part to this controversy: The Patent, Trademark, and Copyright Journal of Research and Education, 4 (Winter 1960); 5 (Winter 1961-62); and 6 (Conference Number 1962).

An excellent summary of the range of views on the question fills an entire issue of the Federal Bar Association publication: The Federal Bar Journal, 21 (Winter 1961).

The U.S. Senate Committee on the Judiciary has conducted extensive studies and hearings on this matter in recent years. For a summary of recent activities, see Patents, Trademarks, and Copyrights, 87th Congress, 2nd Session, 1962, Report No. 1481. (G. P. O.)

An excellent introduction to the broad field of patents was contributed by Fritz Machlup for the Senate Subcommittee on Patents, Trademarks, and Copyrights of the Committee on the Judiciary, An Economic Review of the Patent System, 85th Congress, 2nd Session, 1958, Study No. 15. (G. P. O.)

In addition, the Special Subcommittee on Patents and Scientific Inventions of the House Committee on Science and Astronautics has held lengthy testimony on the patent question. The Subcommittee's present views, together with a good discussion of what the hearings revealed, is presented in Ownership of Inventions Developed in the Course of Federal Space Research Contracts, House, Report of the Subcommittee on Patents and Scientific Inventions of the Committee on Science and Astronautics, 87th Congress, 2nd Session, Committee Print, April 5, 1962. (G. P. O.)

A concise review of the subject has been published by the Government Patent Policy Study Committee organized by the National Council of Patent Law Associations: Statement of Principles for the Evaluation of Federal Government Patent Policy (Washington: National Council of Patent Law Associations, Spring 1962).

A recent Fortune article briefly sums up the controversy and relates it to other current problems present in the patent system. Samuel W. Bryant, "The Patent Mess," Fortune, 66 (September 1962), pp. 111 ff.

8. House, Special Subcommittee on Patents and Scientific Inventions of the Committee on Science and Astronautics, Hearings, Property Rights in Inventions Made Under Federal Space Research Contracts, 86th Congress, 1st Session, No. 47, 1959; and Patent Policies Relating to Aeronautical and Space Research, 87th Congress, 1st Session, No. 20, Part 1, 1961, and 87th Congress, 2nd Session, No. 1, Part 2, 1962. (G. P. O.)

9. Some interesting research on the utilization of government owned patents is underway at this writing. For preliminary findings, see Donald S. Watson and Mary H. Holman, "Government Patent Policies," The Patent, Trademark, and Copyright Journal of Research and Education, 6 (Conference Number 1962), pp. 30-2.

10. Results of a pilot survey of company policy in this regard are described in Joseph Rossman, "Patent Policies for Employees," The Patent, Trademark, and Copyright Journal of Research and Education, 6 (Conference Number 1962), pp. 24-9. For details of the operation of the International Business Machines Corporation's invention award plan, see testimony of G. W. Birkenstock in House Hearings, Patent Policies Relating to Aeronautical and Space Research, No. 20, Part 1, 1961, op. cit. footnote 8, pp. 368-71.

11. Research in this area might be aided by examination of the strong incentives for innovation provided in Western Germany and certain European countries as indicated in Wilson R. Maltby, "A Government Patent Policy for Employee Institutions," Federal Bar Journal, 21 (Winter 1961), pp. 127-45.

12. See for example, "Creativity -- The Facts Behind the Fad," Editorial Reprint of feature articles appearing in Product Engineering, various issues 1955-1960.

13. Aviation Week and Space Technology, 78 (January 14, 1963), p. 59.

14. In this regard, see William T. Knox, Director of Technical Information Division, Esso Research & Engineering Company, statement before the House Committee on Science and Astronautics, Hearings, Dissemination of Scientific Information, 86th Congress, 1st Session, 1959, No. 24 (G. P. O.), pp. 53-62.

15. An interesting description of the flow of technology, accompanied by a chart, in medium to large corporations, is presented in Leslie E. Simon, "Developing Fundamental Knowledge for New Products" in Organizing for Product Development, AMA Management Report No.31 (New York: American Management Association, 1959), pp. 59-61.

16. Interest within industry is growing for by-product exploitation. See for example, "Don't Overlook Byproduct Profit," Steel, 149 (December 25, 1961), pp. 24-6.

17. Merton J. Peck and Frederick M. Scherer, The Weapons Acquisition Process: An Economic Analysis (Boston: Graduate School of Business Administration, Harvard University, 1962), pp. 219-21.

18. Ibid., Chapter 7, "Entry Into and Exit From the Weapons Industry," pp. 190-221, and Appendix 7A, "Small Business in Weapons Research and Development," pp. 626-31.

19. Charles P. Bourne, "The World's Technical Journal Literature: An Estimate of Volume, Origin, Language, Field, Indexing, and Abstracting," American Documentation, 13 (April 1962), p. 159.

20. Ibid., p. 160.

21. Hearings, Dissemination of Scientific Information, op. cit. footnote 14, p. 57.

22. For related ideas, see "Stretching the Research Budget," Dun's Review and Modern Industry, 80 (December 1962), p. 37; also Carl Rieser, "The Salesman Isn't Dead -- He's Different," Fortune, 66 (November 1962), pp. 124 ff.

23. The duplication and waste of effort on the part of researchers unaware that the task has already been accomplished is being recognized as a major problem in the Soviet Union. See Ralph Nader, "Technology: Reds Look West," The Christian Science Monitor, December 17, 1962, p. 10.
Russel Bowen of Arthur D. Little, Inc. [in a paper entitled "Contribution of R and D to the Soviet Armament Industry," delivered at the International Arms Control Symposium, Ann Arbor, Michigan, December 17-20, 1962], stated that 60,000 people are working in scientific and technical information centers in the Soviet Union to help exploit existing knowledge, and to economize on scarce research and development resources. They are concerned with translation, abstracting, and documentation.
For an excellent article examining the utilization of U.S. patents to reduce rediscovery costs, see Peter C. Reid, "The Research You Shouldn't Be Doing: How the Patent Office Can Cut Your R & D Costs," Management Review, 52 (February 1963), pp. 4-13.

24. Bourne, op. cit., p. 159.

25. George P. Baker, [address before the 32nd National Business Conference, Harvard Business School, June 8, 1962, Cambridge, Massachusetts]. Theme of the conference was "Managing the Technological Revolution." An interesting comment on some of the highlights was published in The Executive, 6 (September 1962), pp. 25-9.

26. One attempt to face part of this problem is the "Modern Engineering" cram course initiated two years ago by the University of California at Los Angeles. Running for six weeks, its purpose is to summarize for engineering executives and managers of technically oriented companies the new advances in mathematics, technology, and engineering management. See "Tough Cram Course for the Brass," Business Week, June 30, 1962, pp. 90-4.

27. Addison H. White, "Basic Research at Bell Telephone Laboratories," in Proceedings of a Conference on Academic and Industrial Basic Research, sponsored by the National Science Foundation at Princeton University, November 1960, NSF-61-39 (G.P.O.), p. 25.

28. Quoted from the President's 1963 Annual Economic Report to Congress in The New York Times, Western Edition, January 22, 1963, p. 4.

29. See for examples, AMA Management Reports No. 8, Establishing a New-Product Program (1958), No. 31, Organizing for Product Development (1959) and No. 42, Maintaining the Product Portfolio (1960) (New York: American Management Association); Small Business Administration, Small Business Management Series No. 17, New Product Introduction for Small Business Owners (1955), and No. 19, Technology and Your New Products (1956) (G.P.O.)
See also Philip Marvin, Planning New Products, reprints of 17 articles appearing in Machine Design, various issues 1953-1958 (Cleveland: The Penton Publishing Company, 1958); and Management of New Products (Chicago: Booz, Allen & Hamilton, Management Consultants, 1960).

30. Bernard Barber, "Resistance by Scientists to Scientific Discovery," Science, 134 (September 1, 1961), pp. 596-602, reprinted in Bernard Barber and Walter

Hirsch (eds.), The Sociology of Science (New York: The Free Press of Glencoe, 1962), pp. 539-56.

31. See for example, Optimum Use of Engineering Talent, AMA Management Report No. 58 (New York: American Management Association, 1961).

32. Dr. D.M. Robinson, President, High Voltage Engineering Corp., [address to the conference on "Managing the Technological Revolution," sponsored by the Harvard Graduate School of Business Administration, Cambridge, Massachusetts, June 8, 1962].

33. J.F. Mahar and D.C. Coddington, New Product Development . . . Reducing the Risk, report prepared under a grant from the Small Business Administration (Denver: University of Denver Research Institute, December 1961), pp. 3-5.

34. Some interesting suggestions to alleviate this condition on the part of the administrator are offered by Eric Ashby, "The Administrator: Bottleneck or Pump?" Daedalus, 91 (Spring 1962), especially pp. 274-8.

35. H.M. Vollmer, A Preliminary Investigation and Analysis of the Role of Scientists in Research Organizations, Stanford Research Institute Technical Report, Phase I, February 1962, prepared for Air Force Office of Scientific Research, ASTIA No. AD-275-937, p. 13. The Bibliography, pp. 161-73, provides an indication of the range of research which has been performed in this area.

36. Edward F. Denison, The Sources of Economic Growth in the United States and the Alternatives Before Us, Supplementary Paper No. 13 (New York: Committee for Economic Development, 1962), p. 251.

37. Margaret Mead, "Must Capitalism Crawl," Harvard Business Review, 40 (November-December 1962), p. 172.

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